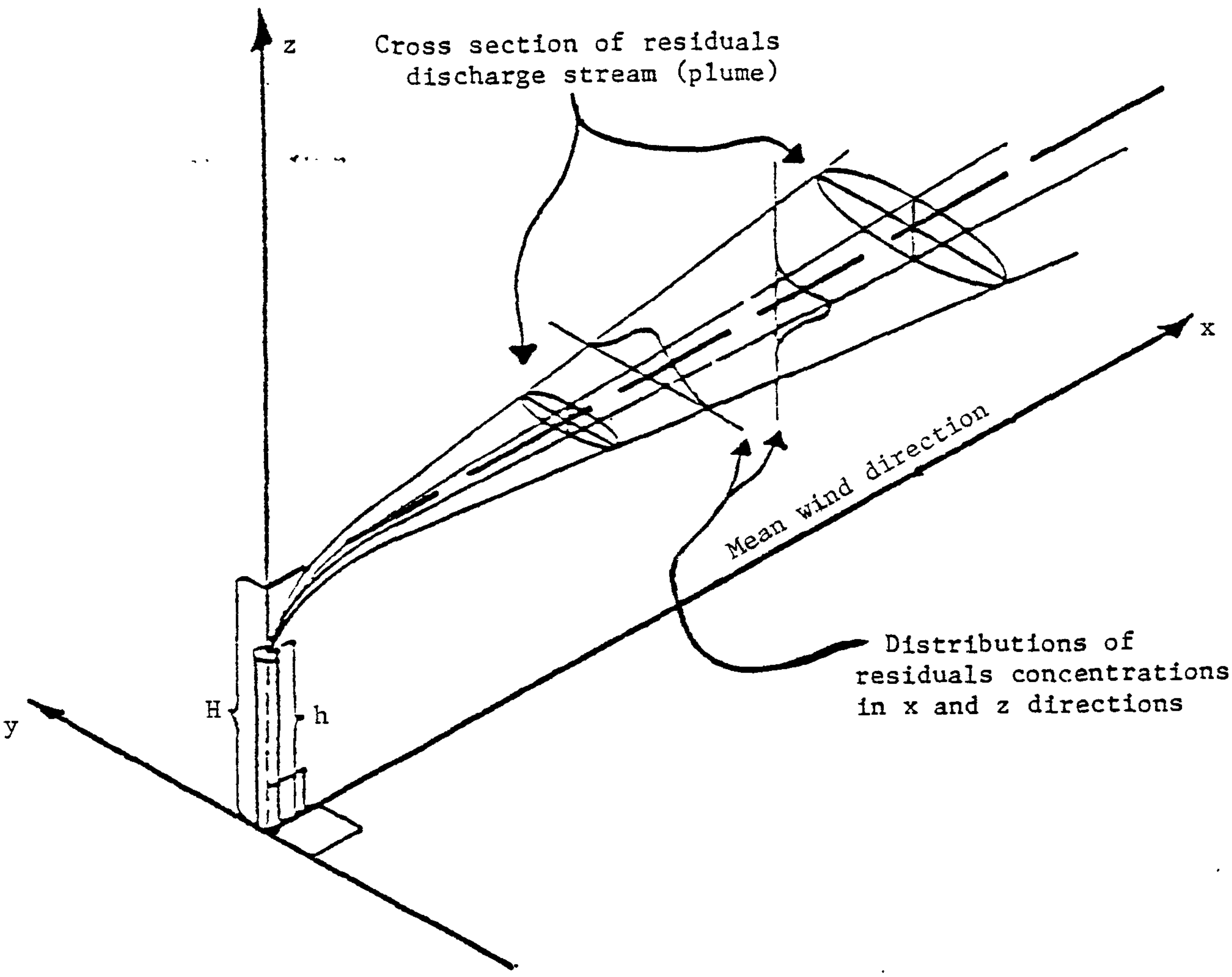
Figure 14. Coordinate System for the Gaussian Continuous Plume Equation
Showing Assumption of Normal Distribution in Each Dimension



Source: D. Basta and B. Bower, eds. 1982. Analyzing Natural Systems (Resources for the Future, Washington, D.C.).

(GP2) At each nonnegative value of x, the concentration profile of the plume is Gaussian in both y and z directions

(GP3) The source term is constant over time

(GP4) The wind speed is constant, and the wind blows in the positive x-direction

(GP5) There is total absorption of the plume at the earth's surface

Those assumptions are plausible if we divide the time over which the fire proceeds into small enough subintervals, so long as those subintervals are long enough for approximately steady-state conditions to be established. The restriction to three-hour subintervals is imposed by the data.

The Parameters σ_x and σ_y in the equations (7.1) and (7.2) are empirical parameters, with values obtained from measurements taken under varying wind speed and meteorological conditions. The latter conditions, together with wind speed, are summarized in a single variable, the stability class, which was developed by Pasquill, (1961) assigned by an algorithm that has come to be known by the name of its inventor, Turner, (1964).

THE ANALYSIS: AN OVERVIEW

So much for a rough descriptive account of the Chemical Control Incident. Now we turn to an overview of the analysis of the following two chapters. Our assumptions about the source release term have been discussed in this chapter's section on Modeling the Transport of Toxics from the Chemical Control Fire and are summarized in table 24. Since these are so critical to the final damage estimate, and so uncertain, table 23 presents a range of source release terms over which we make damage estimates.

In the data appendix for the Chemical Control case study, we describe the meteorological data we use. The important feature of that data is its relative abundance, allowing some simplification in calculating damages. We will use the familiar Gaussian plume model as our underlying atmospheric transport model; but that model cannot be used before we compute, for each meteorological data record, stability class and dispersivity "coefficients" (the latter terminology is conventional, but the coefficients are actually functions). Our implementation of an algorithm for computing stability classes is described in chapter 8's section on A Computationally Efficient Population Grid and figures 16, 17, and 18.

Taken together, those elements can be combined into a computation of ambient concentrations of fire-generated pollutants, and the formula for that computation is given in equations (7.1) and (7.2). From ambient concentrations, and from data on the distribution of population in townships surrounding the Chemical Control site, it is simple, in principle, to compute population exposures, and the relevant equation (8.1) is straightforward. But because we are computing exposures over the course of a fire long enough for shifts in wind speed and direction to matter, some computational tricks are needed; these are described in chapter 8's section on A Computationally Efficient Population Grid. Finally, to go from population exposures to an estimate of the cost of risk bearing, we need both dose-response and value of risk adjustments: those adjustments are described in equation (8.3).

NOTES

1. In 1975, Chemical Control was required to register for an engineering plan for its incinerator with the state's Solid Waste Administration, but neglected to do so. The Administration was lax in enforcing this requirement.

2. Carracino, the former owner, suggested that Conlon and Albert may have made over $7 million in profits during their twenty month tenure (Regenstein, 1982). This estimate may be inflated: even if the new owners charged $200/drum, the buildup of 30,000 additional drums would only yield gross revenues of $6 million.

3. Evaluation of plume samples, however, only give partial information of the properties of the released residuals. Frequent samplings from different parts of the plume would be required to capture any slug effects that could be produced by the diversity of input sources. That is, the release and transport of a highly concentrated mass (a slug) may result with the combustion of a particular substance, and the timing of the combustion of that material thus becomes critical for detection by sampling. If the combustion products from a drum of a toxicant retains its lethal characteristics, the timing of its combustion will affect whether or not it will be detected by sampling.

4. The assumption that all materials are converted into toxic smoke may be an overestimate in that many of the combustion products are innocuous; on the other hand, it may be an underestimate in that the additional mass of reactive atmospheric oxygen is neglected.

CHAPTER 8

THE BENEFITS OF AVOIDING A CHEMICAL CONTROL TYPE INCIDENT

INTRODUCTION

Figure 15 will by now be familiar, in its general outlines, from the other case studies. It is, of course, a lottery representation of the Chemical Control incident. The initial "decision" node represents the community's decision to accept siting of the facility. Thereafter node P1 is situated where the initial release nodes were for the other case studies, and represents the "fire sublottery." There may be no fire, and no incident, as depicted by consequence C1. But in the event that there is a fire, the "meteorology sublottery," represented by the chance node P2, may be critical. Wind conditions carrying toxic combustion products over a wide area may lead to large human exposures. "Favorable" meteorology, on the other hand, may limit such exposures to a small number of individuals in the immediate vicinity of the Chemical Control site.

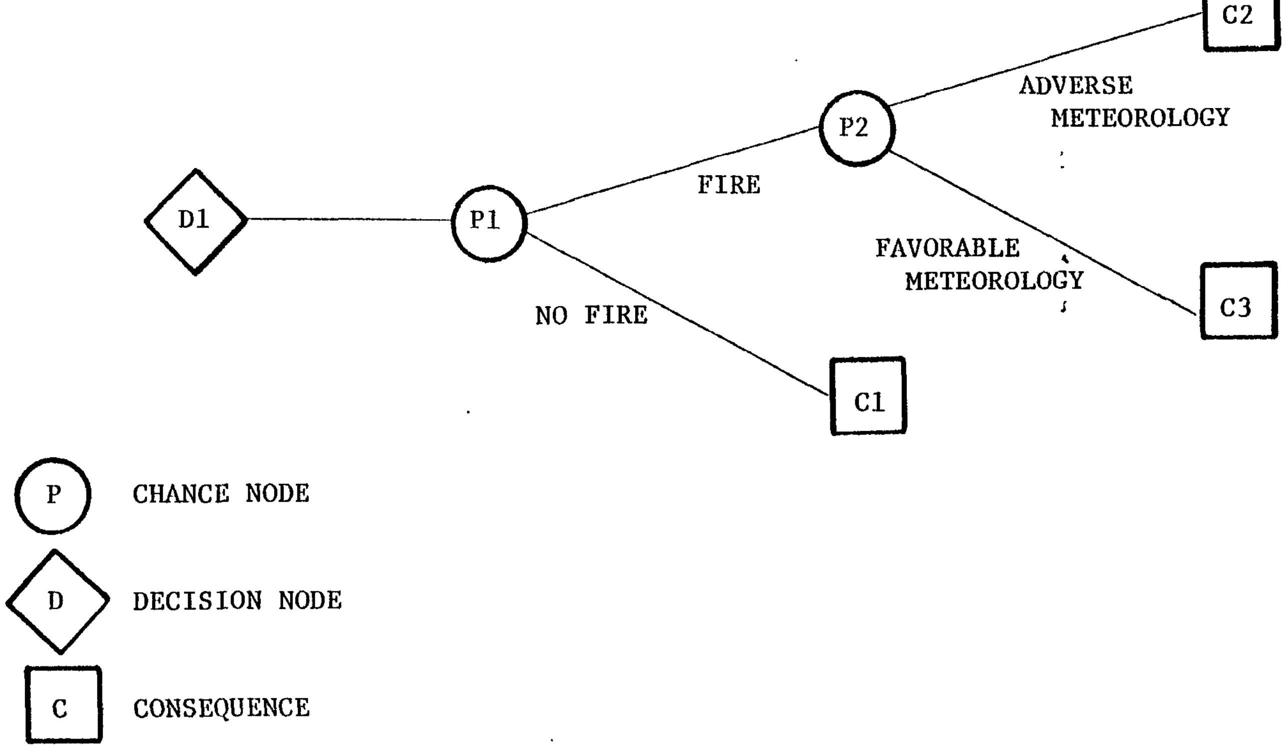
The release sublottery will, as in the other case studies, be treated as parametric. The hard part of our problem, then, is the computation of the "meteorology sublottery," and of the consequences along each branch of that sublottery.

A COMPUTATIONALLY EFFICIENT POPULATION GRID

How should the population density be described so that the Gaussian plume formula can be easily, and efficiently, utilized? Two observations point us to workable answers to these questions. The first is that the Gaussian plume--in fact, the air dispersion process--confines the plume, in each time subinterval in which steady-state conditions are assumed, within a relatively small cone, with base at the origin and centered on the wind direction. Concentrations predicted by the Gaussian plume formula will be very small outside of that cone in that time subinterval, so that computation of the essentially zero concentrations there is wasted computation.

The second observation is that the natural grid discretization of the population distribution is not the customary rectangular discretization, but rather a radial discretization. Over a twelve-hour fire, with three-hour meteorological averages, wind direction can shift at most three times. To compute population exposures over the whole twelve-hour fire,

Figure 15. The Chemical Control Incident Lottery



D1: Lottery accepted; facility sited

P1: Fire sublottery

C1: No fire-related release from landfill

P2: Meteorological sequence sublottery

C2: Substantial human exposures

C3: Insignificant human exposures

the Gaussian plume formula must effectively be computed, with respect to rotated coordinate systems, three times. For a radial population discretization, the coordinates of nodes along the wind direction of course need not be transformed.

Figure 16 depicts the radial discretization of the receptor grid. Because our meteorological data discretizes the wind direction into thirty-six radial directions with 10 degree separations, we have discretized the population distribution at one-kilometer intervals along those thirty-six wind directions.

Consider now the computation of exposures during one particular three-hour subinterval of the fire. In figure 17, we have the nodes at which there are nonzero concentrations of pollutants: they are the nodes along the wind direction, and the nodes on the radials at 10 degrees "above," and "below," that wind direction. The corresponding figure 18 shows how the areal population density is discretized: the population of the cross-hatched area--the intersection of a wedge and an annulus--is assigned to the node at its "center." The populations of the cross-hatched areas are in turn imputed from the known township population densities listed in table 25 and from the correspondence between the township areas of figure 19 and the cross-hatched areas of figure 18. Any particular cross-hatched area is thus composed of several subareas corresponding to particular townships. The population density assigned a subarea is then a weighted sum of population densities, with the weights being the area fractions corresponding to each township.

HUMAN EXPOSURE ESTIMATES

For any particular twelve-hour sequence of meteorological conditions, the transport model of the previous section can be used to compute the corresponding human exposures. The prescription is simple: do the exposure calculation for each three-hour subperiod, and then compute damage as a function of exposures. The latter computation requires no more than an application of the dose-response function.

That function may be additive, in which case our problem is relatively straightforward, or it may be nonadditive, in which case things are more complicated. For the time being, let us stick to the additive case.

Human Exposure Estimates: The Case of Additive Exposures

Here we assume that the dose-response function is linear, so that the relevant "physical" measure of exposure over the twelve-hour fire period is simply the sum of exposures during the three-hour subperiods. Introduce the notation:

POP(i, j)	Population at ith node along jth (radial) direction

Figure 16. The Receptor Grid

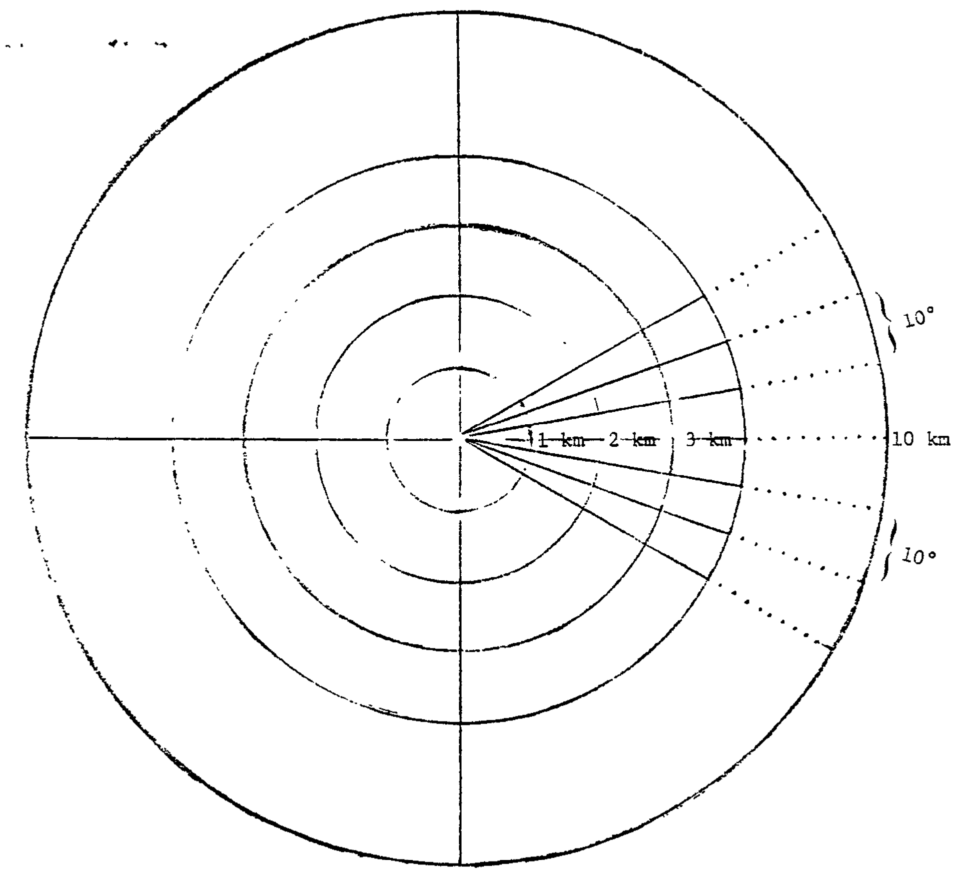


Figure 17. Concentrations Computed at "X" Node Locations for a Given Wind Direction

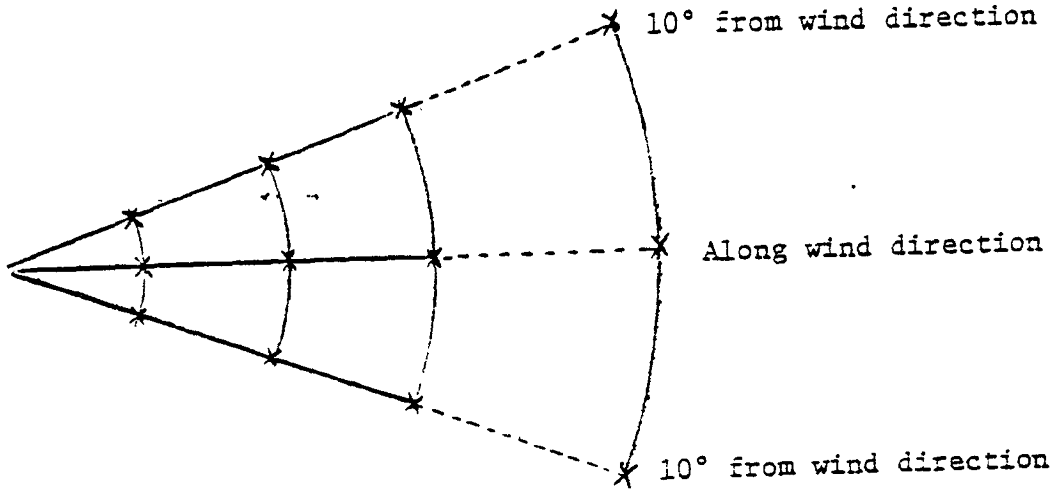


Figure 18. Area Allocated to "X" Node

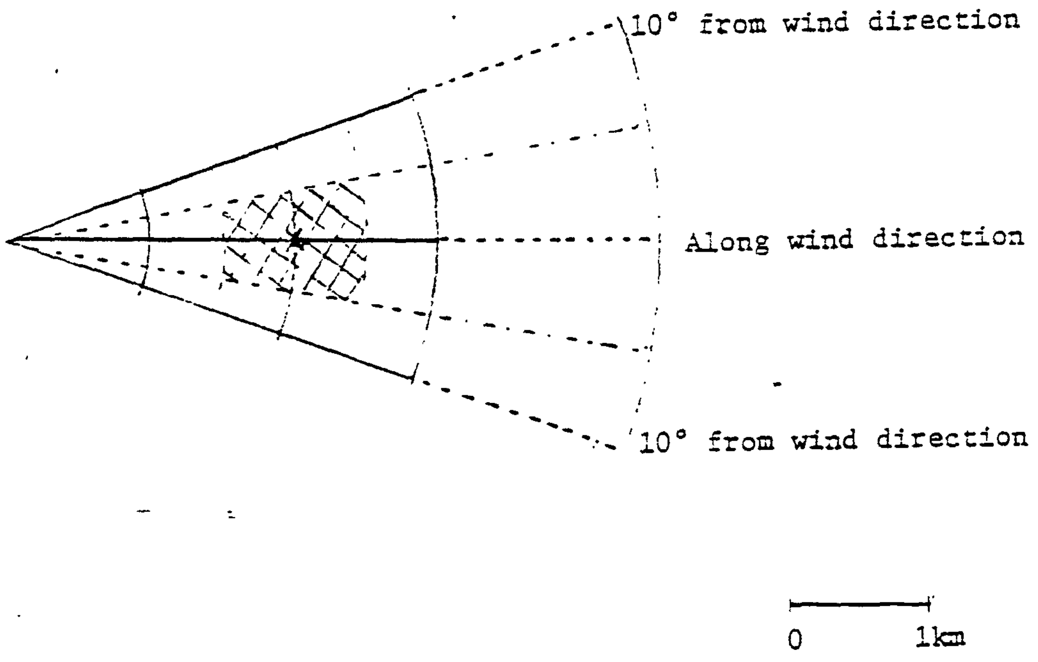
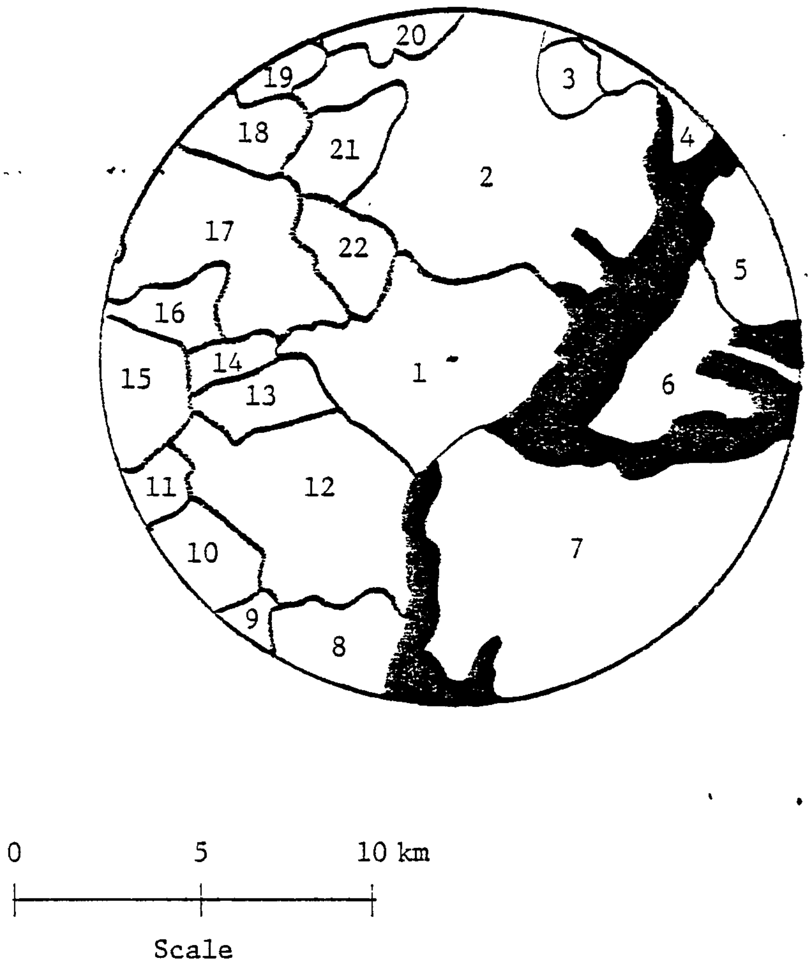


Table 25. Population Density Per Square Kilometer of Townships for 1980

Code	Township	Population Per Square Kilometer
1	Elizabeth	3,600
2	Newark	5,776
3	Harrison	4,897
4	Kearney	1,374
5	Jersey City	5,588
6	Bayonne	3,826
7	Staten Island Burough	2,309
8	Carteret	1,717
9	Woodbridge	1,700
10	Rahway	2,324
11	Clark	1,214
12	Linden	1,304
13	Roselle	2,949
14	Roselle Park	4,459
15	Cranford	2,048
16	Kenilworth	1,644
17	Union	2,281
18	Maplewood	2,700
19	South Orange	2,266
20	East Orange	7,769
21	Irvington	8,785
22	Hillside	3,298

Source: Computed from U.S. Department of Commerce. 1980 Census of Population (Chapter A. Number of Inhabitants. Part 32 (New Jersey) and Part 34 (New York), 1982).

Figure 19. Map of Townships in the Area Surrounding Elizabeth, New Jersey
(For code of townships, see table 25.)



Source: Derived from U.S. Department of Commerce. "Chapter A. Number of Inhabitants, Part 32: New Jersey," in 1980 Census of Population, 1982.

CONC(i, j, t)	Concentration at ith node along jth radial direction in subperiod t
EXPOS(t)	Exposure in subperiod t
TEXPOS	Total exposure

Then definitionally:

$$EXPOS(t) = 3*\sum_{i,j} CONC(i, j, t)*POP(i, j) \tag{8.1}$$

The factor of three arises because each of our subintervals lasts three hours. Put another way, if pollutant concentration is measured in parts per billion, then one unit of "exposure" is defined as one person, breathing one part per billion of pollutant, for one hour.

Since we have assumed that damages are linearly related to exposures, they are linearly related to total exposures, defined as:

$$TEXPOS = \sum_{t=1}^{4} EXPOS(t) \tag{8.2}$$

Recall that the variables EXPOS(t) are random variables, and the sequence (EXPOS(1), ... EXPOS(4)) a random sequence. Thus, TEXPOS is also a random variable, and we must reconstruct its distribution.

ESTIMATES OF THE COST OF RISK-BEARING: A METHODOLOGICAL ASIDE

The data we actually have is data on wind speed and direction, and some other meteorological parameters, for three-hour intervals. If those data represent observations on an underlying joint probability distribution, how shall we estimate the parameters of that joint distribution? More to the point, how shall we estimate expected damages, the quantity we are really interested in?

That question raises a subtle issue. Perhaps the easiest way to pinpoint that issue is with a radically simplified example. First introduce some notation:

T	Random variable corresponding to the scale of an environmental episode
t	Realization of the random variable T
$f(t \mid \mu, \sigma^2)$	Normal distribution of the random variable T

DATA	The observations $(t_1, \ldots\ldots t_n)$ on T
D(t)	Damages associated with an episode of scale T

We assume that the distribution of the scale of episodes is known to be normal, but that the parameters of that normal distribution are unknown; we further assume that D(t) is a known function that is symmetric about the origin, so that

$$D(t) = D(-t) \tag{8.3}$$

In this setting, our question is as follows: how should "expected damages" be estimated?

Here are two candidate answers. The first is the simplest: just write down, by analogy with the usual construction of a sample mean,

$$D_1 = \frac{1}{n} \sum_{i=1}^{n} D(T_i) \tag{8.4}$$

Note that, since the T_i's are random variables, D_1 is a random variable. The second method is more conventional. From DATA, construct estimators $\hat{\mu}, \hat{\sigma}^2$ of the parameters μ, σ^2 of the distribution f. Then define

$$D_2 = \int_{-\infty}^{+\infty} dt D(t) f(t \mid \mu, \sigma^2) \tag{8.5}$$

Again, D_2 is a random variable, since the estimated $\hat{\mu}$ and $\hat{\sigma}$ are random variables.

We suspect that D_1 and D_2 are equivalent in large samples, but are not equivalent in small samples. Since it is characteristic of the major episode phenomenon that samples are relatively small, the difference may matter. How, then, shall we choose between D_1 and D_2?

For our rough empirical work, we will work with D_1, without a full resolution of this issue. Nevertheless, the lines along which such a resolution might run can be sketched. The real difference between D_1 and D_2 is that D_1 is distribution-free, whereas D_2 is conditioned on the assumption that the distribution of T is normal. Thus, the choice between the two estimators must turn on the losses that will result if the assumption on f is incorrect. Finally, take note of one last point: the translation of the random variables D_1 and D_2 into cost-of-risk estimates depends upon whether we are risk-neutral or risk-averse. In the general (risk-averse) case, the cost of bearing the risk associated with D_1 is given by V, with V implicitly defined by

$$u(W_o - V) = E(u(W_o - D_i)) \tag{8.6}$$

In that equation, u is the utility function in wealth and W_o in initial wealth: taken together, u and W_o characterize individual aversion to the particular collective risk associated with an incident like the Chemical Control fire. The expected utility on the right-hand side is computed with respect to the distribution of the random variable D_1.

INITIAL EXPECTED DAMAGE ESTIMATES BASED ON RESTRICTED DATA

Now we turn to the calculation of $E(D_1)$. The results of the exposure calculation are given in table 26. Remember the units of the EXPOS variable: each unit increment corresponds to an additional exposure, to one microgram per cubic meter, for one hour.

From the computed numbers reported in table 26, it is a short (but difficult) step to the damage estimates we want. For those, the exposure figures must be multiplied by an inhalation factor, a dose-response factor, and a value of risk. The resulting cost of risk estimate is

$$CRISK = INDOSE*DORES*VRISK \qquad (8.7)$$

where

$$INDOSE = INTRAN*TEXPOS \qquad (8.8)$$

The factor INTRAN is the fraction of ambient concentration that is effective via the inhalation route, the factor DORES the dose-response "function," here taken as a constant multiplier, and the factor VRISK is marginal willingness to pay to avoid incremental mortality risk. Because dose-response and value-of-risk mulitpliers are subject to so much uncertainty, we will actually do sensitivity on these parameters.

Table 27 reports the results of a preliminary calculation of what is now the array CRISK: the entries of that array give the cost of bearing the risk of the fire, for the corresponding dose-response parameter (row) and value of risk (column). Note that the value of risk range is essentially the same one used in our preliminary analyses of the other case study incidents.

But the dose-response range is new and requires explanation. It is based upon the linear extrapolation of lethal dose estimates for one of the most common and dangerous combustion products, carbon monoxide. Under the linear dose-response hypothesis, that figure can be translated into an incremental annual lifetime mortality risk of 0.45×10^{-6}. More explicitly, if the lethal dose corresponds to a mortality risk of 1.0, or the certainty of death, then the incremental annual mortality risk per exposure unit is the reciprocal of that dose: the reciprocal of 2.2×10^{6} is 0.45×10^{-6}. Because of the many questionable steps, and evident uncertainties, in this procedure, we have chosen to bracket this range with both higher and lower dose-response estimates.

Table 26. Subperiod and Total Exposures, Didactic Chemical Control Incident

CASE 1

Subperiod	Exposure
1	0.90E+10
2	0.27E+11
3	0.90E+10
TOTAL	0.45E+10

CASE 2

Subperiod	Exposure
1	0.18E+11
2	0.45E+11
3	0.90E+10
4	0.90E+10
TOTAL	0.89E+11

CASE 3

Subperiod	Exposure
1	0.14E+11
2	0.36E+11
3	0.14E+11
4	0.72E+10
TOTAL	0.71E+11

Table 27. The Cost of Risk Array for the Didactic Chemical Control Incident for Three Cases;[1] Costs in Dollars

CASE 1

Dose Response	Value of Risk 10**4	10**5	10**6
10^{-4}	0.45E+10	0.45E+11	0.45E+12
10^{-5}	0.45E+9	0.45E+10	0.45E+11
10^{-6}	0.45E+8	0.45E+9	0.45E+10
10^{-7}	0.45E+7	0.45E+8	0.45E+9

CASE 2

Dose Response	Value of Risk 10**4	10**5	10**6
10^{-4}	0.89E+10	0.89E+11	0.89E+12
10^{-5}	0.89E+9	0.89E+10	0.89E+11
10^{-6}	0.89E+8	0.89E+9	0.89E+10
10^{-7}	0.89E+7	0.89E+8	0.89E+9

---

[1]

Assumptions on Source Terms	Case 1	Case 2	Case 3
a) Number of 55-gallon drums	50,000	50,000	40,000
b) Fire duration in hours	9	12	12
c) Percent of mass volatized	50%	100%	100%
d) Fraction of mass burned in 3-hour subintervals	(0.2, 0.6 0.2, 0.0)	(0.2, 0.6 0.2, 0.0)	(0.2, 0.6 0.2, 0.0)

Table 27. Continued

CASE 3

Dose Response	Value of Risk 10**4	10**5	10**6
10^{-4}	0.71E+10	0.71E+11	0.71E+12
10^{-5}	0.71E+9	0.71E+10	0.71E+11
10^{-6}	0.71E+8	0.71E+9	0.71E+10
10^{-7}	0.71E+7	0.71E+8	0.71E+9

IMPLICATIONS AND CONCLUSIONS

The variation in the cost of risk figures in the case tables above is substantial. And there are many ways of constructing a summary measure of those figures, a measure conveying their overall significance. In effect, for any particular value of risk, any subjective probability distribution over the three cases, and any dose-response number, there is a corresponding summary measure.

But for present purposes, let us focus on what we believe is a plausible set of values. Choose the lowest number in the dose-response range, 10^{-7}, the middle of the value of risk range, 10^{+5}, and our case 2, representing our best judgment about the condition of the site prior to, and during, the fire. The corresponding annual cost of risk-bearing is \$0.98 x 10^{+8}, or almost one hundred million dollars. That figure is, of course, unweighted by the probability of the initial release, i.e., the fire. If subjective estimates of the probability of a fire at the site were, say, 10^{-4}, the corresponding incremental annual cost of risk-bearing is \$0.98 x 10^{+4}.

Within this kind of calculus, that estimate would justify annual expenditure of up to about ten thousand dollars on any policy guaranteed to prevent an incident like the Chemical Control incident. Alternatively, if we discount that figure at 10%, a capital expenditure of up to about one hundred thousand dollars would be warranted if prevention of the incident could be thereby guaranteed.

In presenting that estimate, it must be remembered that it is based not only upon many assumptions, but also that we have, for the sake of simplicity, assumed that all individuals are identical, and then multiplied by the number of individuals. In fact, individual valuations of these risks will vary substantially, and it is obvious, but important nonetheless, that those individuals with very high risk valuations will have an incentive to express them.

The cost of measures which could have prevented the Chemical Control incident lies outside the scope of our work, which is concerned with benefit estimation. Nevertheless, some observations about the difficulties of making such cost estimates can, perhaps, be made. For the Chemical Control site, it would be nice to have estimates of the annual cost of at least three kinds of preventive measures: incineration or other neutralization of all flammable materials, enhanced site fire security, and a switch to disposal at alternative sites which are not located close to densely populated areas. Armed with rough estimates of these kinds of costs, a planning or siting commission could use the methods of this and the preceeding chapter in their deliberations about at least the fire hazards associated with facilities like Chemical Control.

CHAPTER 9

SUMMARY, CONCLUSIONS, AND RESEARCH NEEDS

THE CASE STUDIES IN PERSPECTIVE: SOME SHARED FEATURES OF THE INCIDENTS

The three case studies we have completed cannot claim to be representative of our hazardous waste contamination problems. They are among the few such problems for which there is some basis, in data and modeling, for economic damage valuation. And they do cover the range of environmental transport media: air, surface water, and groundwater are represented.

Thus generalization from our three cases is risky business. It is also unavoidable business if we are to get on with the task of improving our understanding of the scope of our problems. What features, then, are shared by these incidents?

Begin with the question of why these, and the other incidents that we considered as candidate case-study incidents, have been noticed at all. The answer may have some bearing on the theological question of just how many problem sites we have inherited from the chemical revolution of the last three or four decades. For our three case studies there are two answers: one for the Kepone and Price cases, and a second for the Chemical Control case.

In the Kepone and Price cases, the incidents were recognized because "canaries" were present. In the nineteenth century, English miners took caged canaries into the pits with them: if the canaries suddenly died, mine gases were reaching dangerous levels, and the pits were hurriedly evacuated. Thus the Kepone case came to public attention because of the acute exposure effects on Kepone production workers at the Life Sciences plant. Without those effects, it is very possible that Life Sciences would still be operating. Similarly, in the Price case, the families taking their drinking water from wells close to the landfill played the role of canaries. When they recognized that something was seriously wrong with their water, Price's landfill could no longer be ignored. The Chemical Control case is of course somewhat different from these two, but for obvious reasons. Because that site is above ground and located in a major urban area, it could hardly avoid being noticed by its neighbors. New Jersey Assemblyman Raymond Lesniak, who has figured prominently in hazardous substance legislation in his state, grew up two blocks from the site.

But even in the Chemical Control case, the "canaries" were poorly informed: that was also true for the Kepone and Price incidents. By that we mean that there was a great disparity between the information held by the site operators and the information available to the affected neighbors. Clearly, it is possible to talk about some notions of equitable risk sharing when there is, in some sense, equal access to information about the risks being shared. Equally clearly, by almost any criterion there was no such equal access in our three cases.

A second and striking general feature of our three case study incidents, and an even more striking feature of some other such incidents, is the relatively small amount of material involved. To begin with the other incidents, the Michigan polybrominated byphynol incident may have involved less than 100 pounds of the chemical, and the Times Beach incident less than 100 pounds of dioxin-bearing waste. Turning to the incidents we have studied, the Kepone incident involved about 20,000 kilograms of Kepone, discharged over about ten years, or about 2,000 kilograms per year, not a huge number for a large batch production operation. Similarly, the total mass of contaminant in the Cohansey aquifer may be as little as 100,000 pounds: over the ten-year period, that is about 10,000 pounds per year. Compared to the kinds of mass emission rates familiar from the more conventional kinds of pollution, these are relatively small numbers.

A second interesting feature of our three case studies is the involvement, in each, of essentially marginal firms: firms, or operations at small scale and, in comparison with the industry leaders, of low competence. It is possible to run pesticide batch-production operations safely, without risk to employees: Life Sciences simply chose not to run such a clean operation, whereas many large, well-managed firms in the chemical industry have clearly made the opposite "correct" choice. Charles Price's individual and rather improvisatory landfill operation bears no resemblance to modern disposal and landfill operations, particularly those found in Germany and the Scandanavian countries. And even from the height at which the aerial photographs of chapter 7 are taken, a summary judgment on the efficiency with which the Chemical Control operation was run is possible.

Third, we take note of the illegality of operations in all of our three case study incidents: every one of them occurred in violation of an existing permit or law. In the Kepone incident, both Allied Chemical and Life Sciences operated in explicit violation of their Virginia Water Board permits. Charles Price's operation, too, clearly violated explicit provisions of his permit from the New Jersey Department of Environmental Protection. And the Chemical Control fire occurred months after New Jersey state authorities had begun to move against the site operator for permit and state code violations.

A fourth general feature of our case study incidents may be described, somewhat awkwardly, with the following phrase: there was substantial preincident government ignorance about conditions at the site, and the costs of gathering information about events subsequent to the incident were very high. For what we really know about conditions in the Life Sciences plant at Hopewell is summarized in the production record and in the observations of exposed workers: that amounts to a little information on emissions, some basis for reconstructing exposure levels, and not much more. In comparison, the information assembled after the incident was massive. In the wake of the Kepone incident, the federal government and the governments of Maryland and Virginia were forced into a massive monitoring and modeling effort the costs of which may have run as high as $5 million. Those efforts included measurements of ambient Kepone concentrations, measures of the body burdens of Kepone in edible species of finfish and shellfish, and bioassays for testing for the carcinogenicity of Kepone in mice. The latter alone can often run as high as several million dollars.

Similarly, the amount and quality of information available to Price and to the general public on operations at the landfill are easily characterized. Price kept almost no records of what was placed in the ground on his site. For the general public, the situation was even simpler: publicly available information on operations at the landfill consisted of the provisions of the permit issued by the New Jersey Department of Environmental Protection. As we have seen, Price's operations violated the provision of that permit in a way that was almost compulsive.

But the situation after the incident was, like the situation after the Kepone incident, very different. The costs of establishing the extent of the problem associated with the Price landfill were very high; the Atlantic City, state, and U.S. Environmental Protection Agency sampling and monitoring programs around the landfill may have cost as much as ten million dollars. The reasons are obvious: geohydrological surveys, well digging, and testing for the presence of chemicals at the parts per billion level are expensive operations.

Finally, the same general argument applies to the Chemical Control incident. Information on what was present in the drums on the site before the fire is thin: we have the names of some chemicals and the names of some of the originating firms. And information on what actually happened during the fire is equally thin: the twelve-hour period of the fire did not allow for much accurate sampling of the plume for identification of its constituents. Had it been possible to organize rapidly for extensive sampling of the plume from the Chemical Control fire, the expense might have been considerable.

THE CASE STUDIES IN PERSPECTIVE: THE DAMAGE ESTIMATES ANALYSES

About all our case studies, we can make the following rather general assertion. Plausible and conservative assumptions about source terms, transport mechanisms, exposures, dose-response functions, and risk attitudes lead to large damage estimates. Put in other words, the gross benefits of policies aimed at preventing, or mitigating, incidents of this kind are large, at least under some plausible assumptions.

This can hardly be surprising: it is improbable that these incidents would have provoked the kind of public attention they have if this were not the case. In making that assertion, we again call the reader's attention to the important issues surrounding individual perceptions of release probabilities, and thus individual perceptions of the cost of bearing the risks associated with these incidents. Were some team of risk-assessors able to produce convincing estimates of release probabilities, and were the population at risk willing to accept those estimates, things would be relatively simple. The correct approach to estimates of the cost of risk bearing would be the standard one described in chapter 2. And in fact, for the more familiar and insurable individual risks, such as the risk of an automobile accident, the existence of actuarial data forces that convergence of probability estimates.

But for the kinds of episodes we have examined, even skilled risk-assessors will have trouble producing credible estimates. For the failure probabilities they seek to estimate refer to unique events, and moreover to events the probability of whose occurrence depends upon the incentives faced by facility operators. Beyond that difficulty is the fact that perceptions of the population at risk regarding rare events seem almost necessarily conditioned by the fact of rarity. It seems implausible that individuals, confronted for the first time with the occurrence of a rare event to which they have hitherto devoted little attention, will immediately register that new event at its true, and rather low, probability. The latter figure might be reached only after a lengthy learning period during which the event in question does not occur again.

That argument makes the connection between the true release probabilities for a major environmental episode, on the one hand, and the perceived release probabilities, on the other, somewhat elusive. But since that relationship is so critical to estimates of the values of policies aimed at preventing or mitigating such episodes, it should be the focus of future research aimed at improving our knowledge of those values. The last section of this chapter attempts to mark out research needs within that general area. It may be safely neglected by those with limited patience, whose interests are in guidelines for, and pointers to, improvements in our hazardous substance policies. The observation brings us to the question of individual incentive.

THE CASE STUDIES IN PERSPECTIVE: INDIVIDUAL INCENTIVES

A striking feature of all three of our case study episodes is what might be called the breakdown of the structure of obligations and incentives we rely upon to encourage individuals and firms to behave "properly." By properly we mean in ways that benefit themselves and the larger community or, more narrowly, do not negligently rain damage upon the latter.

Recall the "specifics of the three case studies. In the Kepone case, Life Sciences was operating in violation of permits from the Virginia Air and Water Boards; operation consistent with those permits would have prevented the incident. In the Price's Pit incident, the same was true: the provisions of Price's permit explicitly barred disposal of liquid wastes. And in the Chemical Control incident, Carracino was, again, operating in violation of permits from the New Jersey Department of Environmental Protection.

What went wrong? Remember the economic rationale for a permitting requirement and process: substitution for a market that "fails" to form, presumably for transaction-cost reasons. It is too expensive for the residents of the jurisdictions surrounding the Chemical Control site to assemble and negotiate an appropriate level of prevention with the site operator. Instead, a public body simply mandates that the site be operated in a manner consistent with such a level of prevention.

Only the threat of punitive action, in the form of loss of an operating permit, or the imposition of a jail term or a fine, or all of the above, are available for enforcement of the conditions of the permit. But simple calculations with the fines imposed in our case study incidents suggest that those instruments are far from adequate to compel adherence to the terms of the permit. The simplest such calculation is the following: under plausible assumptions about abatement (or control) costs and fines, and assuming that management is risk-averse (use logarithmic utility), compute the probability of detection and conviction sufficient to make the decision to control the rational (or utility-maximizing) one. Generally, there is no probability lying between zero and one that compels that decision.

Even remembering our cautions about conclusions drawn from three case studies, the effect of such simple calculations is somewhat disturbing, for if the decision to control is the socially rational one, those calculations suggest that that decision can only be "decentralized" by increasing risk aversion, by increasing fines, or by increasing the probability of detection and conviction.

Perhaps the surest way to do all of these things is through the performance bond instrument. If the potential episode associated with a facility can be anticipated and specified, and if conditions for forfeiture can be clearly spelled out, the latter probability moves close to one. The size of the bond is in effect the size of the fine, and owners and operators are likely to act more cautiously with an identifiable asset at risk.

This general idea is, we believe, worthy of serious and specific attention: it might be instructive to examine how such bond instruments might have been written, ex ante, for each of our case studies. But even such facility-specific instruments cannot bear the burden of adjusting for distorted incentives governing flows of hazardous materials elsewhere in the economy. For that reason, we turn briefly to some broader issues of hazardous substance policy.

THE CASE STUDIES IN PERSPECTIVE: NET BENEFIT ESTIMATES

The objective of our three case studies was estimation of the gross damages, to the environment and to human health, avoidable by policies aimed at preventing or mitigating major environmental episodes. But the reader will have noted that, along the way, we have intermittently strayed over the line into discussions of the cost of assessing and mitigating those episodes, and the costs of enforcing the law and imposing the specified penalties.

Any study of the net benefits of prevention mitigation policies would necessarily deal much more directly with those magnitudes. And that treatment will inevitably face several thorny practical and conceptual issues raised by those cost categories. The prevention-cost category is relatively simple and unambiguous. A policy which can prevent a particular episode category is, conceptually, exactly a payment for avoiding the corresponding lottery, with the latter word used in the sense we have given it in our case study chapters. If the alternatives are prevention, on the one hand, or bearing the episode lottery on the other, the relevant net benefit figure is exactly the differential between willingness to pay to avoid the lottery and the cost of prevention.

The mitigation case is somewhat more complicated. In practice, "mitigation" is difficult to define. The simple notion of "restoring the situation prior to the episode" is difficult to specify. In the Kepone case study, for example, what would restoring the James to its original condition mean? Presumably, "reducing Kepone concentrations, in bottom sediment and in the water column, beyond the level of detectability with current analytical technology" that, at least, is a definite standard. In the Price case, a similar standard might be articulated: reducing concentrations of all priority pollutants in the Upper Cohansey aquifer below some preassigned health-effect threshold levels.

Both of those standards are of course likely to change over time, as analytical methods improve and as perceptions of thresholds change. But they also must be made probabilistic in order to be operational. For insuring that all James estuary bottom sediment is free of Kepone is impossible, or infinitely costly. A similar point can be made about the Cohansey aquifer: short of pumping and cleansing all water currently resident in the aquifer, there can be no assurance that some slugs of contaminants have not been overlooked.

Thus strict interpretations of "mitigation" are likely to lead to huge estimates for mitigation costs. This is in fact true for the two case studies for which ex post mitigation is a possibility. In the Kepone case, the Environmental Protection Agency's feasibility studies estimated the cost of mitigation, by dredging the James bottom, at roughly one billion dollars. And in the Price case study, the costs of cleanup via pumping, cleansing, and reinjection were estimated to be in the tens of millions of dollars.

Suppose, for the sake of argument, that in each of those cases the costs of mitigation substantially exceed plausible estimates of the value of service flows for the resource. In the Kepone case, suppose that the present value of service flows from the James is less than one billion dollars, and in the Price case, suppose that the present value of water supplies from the Upper Cohansey aquifer is less than ten million dollars. In both of those cases, the "economically rational" decision, in the pose episode case, would be to "scrap" the associated resource. Specifically, assuming that future human health damages could be avoided by closing or posting the sites, the corresponding service flows of the James estuary and the Cohansey aquifer would be written off as lost. Rather than incur the costs of mitigation, cheaper substitutes would be bought.

That conclusion should not be confused with the conclusion relevant to a very different situation, the situation prevailing before an episode occurs. Communicating to the owners and the operators of facilities which may be the case of episodes of the kind we have studied, an upper bound on potential liability based upon current replacement cost may be the wrong thing to do. There are at least three reasons. First, the assumption that future human health damages can be avoided by posting may be unduly optimistic. Second, current replacement cost may understate (or may overstate) true "economic" replacement cost: the latter is the relevant cost concept. Third, individual owners and operators may discount the potential post-episode liability by the probabilities of detection and conviction. The latter probabilities are likely to be very low for some sequences posing great danager of human health risk: low-level exposures over long periods.

HAZARDOUS SUBSTANCE POLICIES: SOME RUMINATIONS

There is, as we have already noted, little basis in our three case studies for generalization across similar incidents or similar facilities. And there is certainly no basis for far-reaching conclusions regarding hazardous substance policy.

But because those policies are presently at the center of national attention and public concern, and because there has been considerable general learning about this terrain in our three case studies, let us say what we can, and point to places where others may be able to say more.

Let us agree to speak somewhat loosely about a class of substances called "hazardous substances," and about "hazardous substance policy." In so doing, we overlook what some consider endearing anomalies and others view as signs of collective mental incapacity. We refer, of course, to the existence of several substances which, though almost certainly hazardous by any objective criterion, have eluded official classification as such. Gasoline, ubiquitous in our society and both volatile and rich in dangerous polycyclic aromatic chemicals, seems involate. Tobacco, perhaps the substance for which the epidemiological evidence of a link with cancer is least ambiguous, bears the stigma, in advertisements, of a Surgeon General's warning. But that warning seems only to have relieved the cigarette companies of all liability for cancer induction, and with tobacco explicitly excluded from regulatory consideration in the early sections of the Toxic Substances, Control Act, consumption marches on.

Of course, there is a simple explanation: society reaps immense benefits from gasoline. And, for whatever reason, smokers perceive benefits from their tobacco consumption. Moreover, there is no serious argument with the cliche that there are corresponding benefits associated with the use, in production and consumption, of many other hazardous substances: those benfits are, for the most part, successfully internalized by the market.

But that is not true of the costs, including the cost of risk-bearing, associated with many of those substances. And one way to look at many of our policies governing the use of hazardous substances is as arrangements for guaranteeing a more tolerable, and fairer, distribution of those risks and costs than the unassisted market would provide.

At the center of our arrangements for allocating the risks and costs of dealing with hazardous substances are three major pieces of legislation: the Toxic Substances Control Act (TSCA), the Comprehensive Emergency Response, Control and Liability Act (or "Superfund"), and the Resource Conservation and Recovery Act (RCRA). The Superfund is, in a sense, entirely "backward looking": it was created to speed the cleanup of contaminated sites that are the result of our past negligence or worse. But one provision of the act calls for treble-damage suits to recover the value of damages to natural resources. That provision, if enforced, is certainly a powerful incentive to avoid the worst kinds of waste-disposal practices. The Price landfill site is in fact one that was to receive priority attention under the Superfund.

TSCA, which establishes the framework for regulating chemicals, is part backward-looking and part forward looking. Under TSCA, an inventory of chemicals in commerce was drawn up: chemicals introduced after that date were required to pass though a premanufacture notification procedure, so that chemicals which might threaten human health or the environment could be subjected to additional testing. In principle, if the results of those tests are positive, plans to introduce the chemical in question into commerce can be reconsidered before there is an enormous commercial and societal interest in continued manufacture and use. The premanufacture notification procedure is the "forward-looking" component of TSCA.

While TSCA attempts to catch hazardous substance problems at the start of the production-consumption-disposal cycle, RCRA aims at correcting the problems that have arisen at the end of that cycle, when hazardous wastes are processed for ultimate disposal. Two of our case study incidents, Price's Pit and Chemical Control, arose at this last, "ultimate disposal" stage.

It is far too early to render any serious judgment on the way these newly created arrangements have worked, and are likely to work in the future.

But there are reasons for concern. At this writing, the Superfund is embroiled in charges of mismanagement, political manipulation, and worse, and progress on even those sites that have been targeted for cleanup seems to have been slow. TSCA, too, seems to have produced very little, given the level of funding the program enjoyed during its early years. In particular, very little testing of new chemicals was mandated, and the information submitted to the Environmental Protection Agency under the premanufacture notification program is in many cases too thin to sustain judgment.

While all of those difficulties may be transitory and matters of the moment, there is the possibility that they are not. Specifically, the legislative mandates for hazardous substance policy were passed after major legislative authority for the regulation of air and water pollution came into being. For that reason, much of the hazardous substance problem may have been shifted into the land disposal problems which are the target of the Superfund. Because all residuals streams are to some extent related and substitutable for one another, policies restricting the flow of hazardous substance residuals to one disposal medium will simply increase the flow of those residuals to the other media. And there is some evidence that we have not got the balance right. Many argue that regulations restricting the incineration of hazardous residuals, a process that can neutralize them and make them safer for land disposal, are so tight that more dangerous land disposal has in effect been encouraged.

But even if we ultimately do get the balance between flows of hazardous materials into the three media right, there will still be a need for something like RCRA. While neither TSCA nor the Superfund would have prevented the three case study incidents we have examined, their difficulties, in a general way, may come to plague RCRA, the program that might have helped. The Superfund seems to have foundered on the failure to draw a sharp enough line between our past mistakes and our future problems, and perhaps also on traditional distributive politics. And TSCA's troubles seem to originate in mistaken judgments about the ease with which information can be centralized, and upon the combination of bureaucratic incentives and technical regulation.

RCRA AND FUTURE MAJOR ENVIRONMENTAL EPISODES

Under RCRA, all disposal facilities will, within a few years, have to have passed rigorous technical standards aimed at protecting the health of the local community and at limiting the environmental impact of the plant. There seems to be little quesiton that such facilities can be operated safely and with minimal environmental impact. The real questions seem to be: will they be so operated, and will the communities in which such facilities are sited believe that they will be so operated?

The newer facilities currently being proposed will required large capital investments. If either local or national regulatory authorities have a credible threat of closure, there will be a strong incentive to operate those facilities safely. But threats of closure to be exercised only after a major problem develops are relatively idle threats: the problem lies in guaranteeing proper operation so that major problems do not develop.

That has, in other cases, proven difficult. The temptation is strong to attempt to impose such guarantees by promulgating technical standards for facility operation. From the point of view of the promulgating regulatory agency, there is every reason to push the development of those standards to a point where there can be no reasonable allocation of blame to the agency when, and if a problem arises.

It might be though that this is only a matter of cost, and of pushing somewhat further along a tradeoff between cost and safety. But that is not so. Regulation by technical standard tends to have its own dynamics, or rather its own "statics." Standards once promulgated tend to remain standards, and may impede the development, and the commercialization, of improved technologies for waste treatment and disposal. Perhaps even more important, it is very difficult to control "plant safety" by promulgating technical standards for plant operating practice. The way in which a facility really operates, and its safe operation, often depend upon intangibles of operating practice and operator morale that can be captured only very imperfectly in formally promulgated standards.

Having said that, we return to the question of belief: what will the community contemplating the siting of a new hazardous waste disposal facility think of its prospects? There is no doubt that popular images of what is in store for any such community have already been rather firmly fixed in the public mind by incidents of the kind we have examined. As we have argued, the firms and facilities responsible were marginal, in scale and competence, and operated in an incentive environment that makes what finally did happen less than surprising. The exposed populations in the incidents we have examined learned, after the fact, about the risks to which they had been exposed.

Even if these features of our case study incidents are irrelevant to the newer facilities being proposed for permitting, their images will remain a potent force in the permitting process for many years to come. That can only be changed if accurate information about the newer facilities is relatively accessible, even to critics and opponents of the siting of those newer facilities. And the siting process can only go forward, so that hazardous waste disposal capacity is upgraded, only if there is the general belief that the remaining risks from the facilities are being equitably shared.

For from one perspective, that was the problem with the facilities that led to the incidents we have described and studied. The owners and operators of those facilities privatized the benefits, but externalized, or socialized, the costs, and particularly the risk-bearing costs, of those facilities. They were able to do so, for the most part, by failing, through omission or commission, to inform the community at risk of the nature of their operations.

In the future, siting will require more open risk-sharing arrangements, more openly arrived at. The permitting process will guarantee that rents will accrue to the newer facilities that are permitted and sited. And some of those rents will necessarily be transferred to the host communities, in the form of tax-base contributions. Until both perceptions about the hazards posed by such facilities and the true hazards stabilize, that may be the best we can hope for. It is our hope that the methods devised and explored in this volume will be of some help to participants in that process as they work toward articulating their concerns, and toward risk-sharing agreements that they can agree upon as mutually advantageous and fair.

RESEARCH NEEDS

Looking forward, perhaps overoptimistically, to a period over which that transition occurs, what can and should be the contribution of research and analysis be? The answer depends upon the perspective adopted. It is possible to stand outside the process, and try to understand how that process works. And it is possible to become an active agent in smoothing that transition period. The two perspectives complement one another, but they are usefully distinguished.

From the first perspective, perhaps the most important element in understanding how the process works is understanding how individuals, and the public at large, form impressions of the risks posed by particular facilities and technologies, and how those perceptions are implemented in the political process. Recall that all estimates of the cost of risk bearing ride on essentially subjective estimates of the probability that the episode, or incident, imposing the particular risk does occur. And for episodic, or definitionally intermittent events, here is no natural learning process forcing perceptions of those probabilities toward any actuarial value, if indeed there is any such value.

In chapter 2, we lumped all the intriguing ideas about the ways individuals form their risk perceptions under the heading "anxiety," and then parsed anxiety into several interpretations with very different theoretical properties. That inquiry is extended, still to little more than a beginning, in appendix E. For present purposes, consider only the most intuitively plausible argument for individual risk perceptions far higher than "actuarial" probabilities. Prior to their occurrence, little attention or cognitive effort is given rare events. After an initial occurrence, those events are placed on a cognitive agenda, and ranked, in probability, along with more familiar hazards. Thus, at least for a time, their probabilities may seriously overestimated. During that time, the cost to individuals of bearing the risk is considerably higher than the cost that would be computed based on "actuarial" probabilities.

It seems likely that something like this effect is at work when individuals in a community object, vehemently and sometimes even violently, to the the siting of a facility which, "on average," seems to have been rather safe. Moreover, reports by the media of accidents of one kind or another which are even vaguely related to the facility in question seem to reinforce the initial accident-probability overestimate. Most of us, and even those of us who are trained in probability and statistics, have a hard time pinning down the true population relevant to making inferences about some particular event: many things that seem related may in fact be quite independent, and may therefore offer no useful information about the event of interest. Thus it may be the case that the information that a particular chemical has been found carcinogenic is relevant only to the carcinogenicity of other chemicals in a particular class, of which it is a member. Nevertheless, that conditioning information is intrinsically harder to convey than the simple fact of carcinogenicity. And conveyance of that simple fact often is registered in a way that is misleading about many other chemicals.

Arguments such as these seem more plausbile, and certainly more testable, as accounts of certain kinds of public concerns than others that have been proposed, such as Aaron Wildavsky's thesis that there have been an all-around increase in paranoia. But sharpening and testing ideas such as these will require a greater degree of collaboration between cognitive psychologists and utility and risk theorists. Thus far, the early returns on such collaborations are a few candidate heuristics, suggested methods individuals use for organizing their risk perceptions. We still know relatively little about the properties of even those very simple heuristics.

Finally, return to the second broad perspective we identified: the view from within the process of change in our institutional arrangements for managing the neutralization and disposal of our hazardous materials. Recall the general development we envisioned. The states would help in the organization of regional hazardous waste management authorities, and would allow, through the permitting process, for those authorities to earn rents. The host communities for the new facilities would, in effect, bargain for compensation for the cost of risk bearing, by bargaining for those rents. Over time, and with experience with the new facilities, risk perceptions and risk realities would converge. In the end, we would be left with disposal facilities earning small, or zero, rents, but fully compensating the host communities for the risk borne by those communities.

That process will work to the extent that the parties to the process are constrained, in their aspirations and demands, by considerations of fact and feasibility. This, we suspect, is where the new discipline of risk assessment can make its greatest contribution. The kinds of models and calculations explored in the case studies can easily be turned to the purpose of exploring a variety of hypothetical situations and their consequences. Advances in microcomputers and interactive graphics over the past ten years have made possible for that exploration to proceed in the real time of the planning, or bargaining process. Thus the cost of negotiating risk-sharing agreements between the operators of waste disposal facilities and elements of the host community, or their political representatives, may now be tolerable, and may even be quite modest. In such agreements may lie our best hope for avoiding future major environmental episodes.

APPENDIX A

OTHER CANDIDATE CASE STUDIES CONSIDERED

INTRODUCTION

In recent years, several striking episodes of environmental pollution have received considerable attention: Kepone pollution of the James River in Virginia and the Love Canal incident in New York State are among the prominent examples. Some of those episodes have shared several distinctive features. The onset of the problems has often been sudden, or recognition of the problem has frequently been late in coming, so that there is comparatively little time for individuals and firms to make the required adjustments. And anxieties about the incident may be a major, albeit a psychological, aspect of the burdens imposed by the episodes.

For these and other reasons, rigorous and quantitative analysis of the damages imposed by such episodes may require data and information, and some conceptual work, distinct from the corresponding requirements of analyses of the more familiar kinds of environmental degradation. Under Cooperative Agreement CR 807 901 010 between Resources for the Future and the Environmental Protection Agency, Resources for the Future estimated the damages associated with the Kepone incident, and then performed several subsequent case studies. Those damages translate, as damages avoided, into benefits of policies aimed at preventing or mitigating such episodes.

In this document, we list those candidate case studies that were considered, but ultimately rejected in favor of others. Each candidate incident is identified and some descriptive material is presented. That descriptive material includes what we were able to learn about the kind, and the quality, of information and data available on the particular incident.

THE INCIDENTS

Glen Cove, Long Island, New York

In early 1977, New York State established maximum permissible concentrations for carcinogens in drinking water: no more than 50 ppb of any single carcinogen, and no more than 100 ppb of carcinogens in total, are allowed.[1] In June 1977, testing results showed contamination of several wells in Glen Cove, a north shore Long Island community. The mayor of Glen Cove ordered four affected wells closed.

Table 28. Glen Cove, Long Island

	Information and Data Sources	Comments
Sources of Pollution		
Initial Release	N.Y. State Department of Health and Department of Environmental Conservation estimates; the 208 study noted below. Data is also available from the County Health Department on monitoring program.	Sources are nonpoint and various; well, cesspool additives, spills, waste discharges by area industry, gasoline tank leaks, pesticide runoff, etc.
Secondary Sources (Aquifer Water)	Extensive sampling done by both county and EPA. Section 208 (Federal Water Pollution Control Act) grant in 1975 to locate the source, and evaluate the seriousness, of the problem.	
Transport Mechanism		
Transport in Aquifer	The U.S. Geological Survey has done considerable work on aquifer here (see USGS Bulletin 62). County Health Department has also done a study.	
Damage Categories		
Health Effects	State estimates one additional cancer in 100,000-1 million people drinking 2 liters/day of water for 70 years.	
Capital Losses	Major losses suffered by town of Glen Cove from need to immediately replace water supplies; estimates of cost of alternative water supply system available from town.	

Water was purchased from neighboring communities at a cost of $1,000 per day, and a water emergency was declared. Glen Cove began to search for alternative sources of water supply, such as treatment of water from the contaminated wells and drilling new wells.

Lathrop, California

The Occidental Chemical Company's facility in Lathrop, California, has been the source of extensive environmental contamination and potential human health problems in the town of Lathrop. For many years, Occidental and its predecessors have dumped chemical and radiological wastes into unlined ponds, a lined pond, ditches, and other disposal areas in the Lathrop facility. Liquid and solid wastes from the manufacture of pesticides and fertilizer products at the plant have percolated downward through the soil, causing pollution and contamination of the underlying shallow groundwater. This shallow groundwater, the top layer of which lies approximately seven to twenty-four feet from the surface, generally migrates in a northerly direction from the Lathrop facility toward the cities of Stockton and Lathrop. Polluted groundwater from the facility's disposal areas has, in the course of migration, reached groundwater that is the source of drinking water for the Lathrop County Water District. The District's wells are located approximately 1.5 miles from the facility and serve more than 3,000 persons. In addition, other local domestic and public water supplies in the district have been affected.

Occidental Chemical Company is a wholly-owned subsidiary of Hooker Chemical Corporation, whose parent company is Occidental Petroleum Corporation. Its main production facility, located in the town of Lathrop, lies approximately ten miles south of Stockton, California, and 1.8 miles east of the San Joaquin River in San Joaquin County. The plant is bordered by an automobile glass manufacturing plant, a dairy farm, two streets, and the outskirts of Lathrop.

The company and its predecssors have manufactured, formulated, and handled pesticide and fertilizer products at the Lathrop facility since 1953, when the original Best Fertilizer Company plant was constructed. In 1963, Occidental acquired Best and has continued to produce pesticides including dibromochloropropane (DBCP until 1977), heptachlor, hexachlorocylohexane (BHC), the gamma isomer of which is commercially known as Lindane, s,s,s-tributyle phosphorotrithioate (DEF), chlorodane, dieldrin, ethylene dibromide, dimethoate, and 1,1,1 trichloro-2, 2-bis (p-chlorophyenyl) ethane (otherwise known as DDT, and still manufactured in the United States for export). In addition Occidental has produced a wide range of fertilizers such as sulfuric, phosphoric, and flurosilicic acid, ammonia, ammonium phosphate, and ammonium sulfate. Gypsum (also known as calcium sulfate) is produced as a fertilizer by-product.

As long ago as 1960, the California Regional Water Quality Control Board issued a resolution prohibiting Occidental's predecessor, Best Fertilizer, from discharging chemical wastes which would cause the level of inorganic

Table 29. Lathrop, California

	Information and Data Sources	Comments
Sources of Pollution		
Initial Release	Wastes deposited in unlined ponds since 1953.	
Secondary Sources (Aquifer Water)	California State Regional Water Quality Control Board ordered Occidental Petroleum Corp. to survey the area and report findings (Ca. Reg. Order 79-76). Study done by Barr Engineering Co. Several other studies of area water quality are also available.	
Transport Mechanism		
Transport in Aquifer	The above study also included a report on movement in aquifer. Data also available from Lathrop County Water District.	
Damage Categories		
Health Effects	No acute effects known. However, 45.7% of Occidental employees accidentally exposed to DBCD in company water have reduced or nonexistent sperm counts. Possibility exists for linkage to water pollution.	
Capital Losses	Property values may have declined. Groundwater is also the prime source of domestic, agricultural, and industrial water in the valley.	

chemicals in usable groundwater to exceed permissible limits or otherwise pollute ground or surface waters so as to be deleterious to human, animal, or aquatic life. In 1968, this resolution was reissued to Occidental.

Since then, a host of hazardous chemicals have been discovered in the vicinity of the facility, and some of these have migrated from containment ponds and disposal areas to the Lathrop County Water District wells. Among the on-site disposal facilities are an unlined pesticide waste pond, six unlined gypsum ponds, an unlined concentrator pond that cools phosphoric acid plant concentrator, a hydraulic asphalt-lined rainwater runoff pond, a cooling pond disposal ditch used to transport pesticide wastes from the plant to the pesticide pond, and a "boneyard" disposal area where solid pesticide and heavy metal catalyst wastes have been disposed.

Hazardous wastes that have migrated to the Lathrop District drinking wells and have been found in detectable levels include the following: DBCP, a known animal and suspected human carcinogen which causes sterility in males, Lindane, a toxic pesticide and known animal carcinogen which drastically affects reproduction in animals, and DEF, which damages the central nervous system. Alpha radiation from uranium in gypsum ponds has also been detected in the Lathrop water supply, water wells, and irrigation wells; alpha radiation exposure can cause leukemia. Among the chemicals detected in the soil at the facility, and/or in the groundwater, are chlordane, dieldrin, heptachlor, ethylene dibromide, dimethoate, and DDT. these are toxic and are known animal carcinogens. concentrations of sulfates and nitrates exceeding the Regional Water Board's limits have also been found in production wells in the vicinity of the Lathrop facility.

The Justice Department, acting for EPA and with the state of California, filed suit in Federal District Court in Sacramento on December 18, 1979 against Occidental and its parent corporation, charging that the company's discharges pose an "imminent and substantial endangerment to health and the environment" and will continue to do so in the future.

Occidental is specifically charged with having taken inadequate account of possible environmental dangers from its waste deposits over a period of years in unlined or inadequately lined ponds and other disposal areas, with failure to take adequate precautions to prevent waste migrations and ultimately contamination of agricultural, industrial, and domestic water, and with failure to report its discharges of pesticides and radiological substances.

The suit asks the court to enjoin the company to complete cleanup measures by July 1, 1981 to prevent further migration of groundwater contaminants. The measures include implementation of a comprehensive plan to determine the extent of pesticide, chemical, and radiological contamination of nearby groundwater and soils, immediate and perpetual monitoring of contaminants to verify that the migration has ceased, evacuation of hazardous waste materials and contaminated soils from various disposal areas, curtailment of hardous, liquid, and solid waste storage for any period in excess of 6 months, cessation of the discharge of pesticide, chemical, and other wastes to surface water, groundwater, or land, a guarantee to the state of sufficient funds to cleanup, and provision of drinking water to any users whose water supply is contaminated by discharge from Occidental/Hooker's Lathrop facility. In addition to this injunctive relief, the suit asks for financial reimbursement to California and the U.S. for costs incurred in determining the extent of the public health and environmental threat, and for substantial civil penalties to the state of California for continuing violations of the Regional Water Board's orders.

Stringfellow Disposal Site, Riverside County, California[3]

The Stringfellow Class I Disposal Site landfill contains a wide variety of industrial wastes (primarily spent acids and caustics), totaling approximately 32,000,000 gallons in 19 years. Contamination of groundwater has occurred from leachate and surface runoff. The state legislature in 1978 appropriated $370,000 for closure and maintenance of the Stringfellow site by the Santa Ana Regional Water Quality Control Board. The costs of final closure--closing the site to new wastes, covering the site, and monitoring groundwater surrounding the site--are now estimated at $20-40 million.

On March 5, 1980, the Regional Response Team determined that Stringfellow was leaching wastes to the Santa Ana River, and in imminent danger of major structural failure. $290,000 in 311(k) funds[4] was spent over ten days to remove 4 million gallons of wastewater, reinforce containments, and repair the access road. Leachate was controlled, and there were no major discharges.

Waste recieved primarily wastewater treatment, dilution, and was then discharged through an ocean outfall.

Acton, Massachusetts

During extention work on the Metropolitan Boston Transportation Authority, workers discovered contaminants in the area being surveyed. An investigation traced them to dumping by the W. R. Grace Company (a company study disputes this). Wastes had been dumped at the site in question since 1942, and the location of the site--on a wetland and near a creek-were also cause for concern. The location of a reservoir which supplied Cambridge--only 2,000 feet from the site--also created problems.

Forty percent of Acton's water supply has been cut off since December 1978 because of the contamination by benezene, trichloroethylene, toluene, and other organics.

Woburn, Massachusetts

A hazardous waste disposal site in Woburn, Massachusetts, is under investigation in what may be one of the oldest chemical disposal areas in the country. The site, located in the northern section of the town, covers

Table 30. Stringfellow Disposal Site, Riverside County, California

	Information and Data Sources	Comments
Sources of Pollution		
Initial Release		
Secondary Sources (Aquifer Water)	1977 study done by Regional Water Quality Board.	
Transport Mechanism		
Transport in Aquifer	See above study.	
Damage Categories		
Health Effects	No major health effects known from site.	
Capital Losses	Potential loss of both ground and surface water supplies.	

Table 31. Acton, Massachusetts

	Information and Data Sources	Comments
<u>Sources of Pollution</u>		
Initial Release	Town did a study on source and level of contaminants.	
Secondary Sources (Aquifer Water)	W. R. Grace Company study and Massachusetts Department of Environmental Quality Study; also town study mentioned above.	
<u>Transport Mechanism</u>		
Transport in Aquifer	Town study also included monitors of movement in aquifer.	
<u>Damage Categories</u>		
Health Effects		
Capital Losses		

Table 32. Woburn, Massachusetts

	Information and Data Sources	Comments
<u>Sources of Pollution</u>		
Initial Release		
Secondary Sources (Aquifer Water)	Massachusetts state agencies have estimated.	
<u>Transport Mechanism</u>		
Transport in Aquifer	USGS and Massachusetts state agencies.	
<u>Damage Categories</u>		
Health Effects	Massachusetts Department of Public Health has analyzed data on cancer mortality for the area. Death rates have been significantly higher for some cancers (notably leukemia). Additional work is planned to attempt to correlate this with chemical exposure.	
<u>Capital Losses</u>		

approximately 800 acres. Historically, the area has been inhabited by many industries known or suspected to have used dangerous chemicals. A portion of the site was occupied by Merrimac Chemical, a company which supplied acids and other chemicals to regional textile, leather, and paper industries. Over the years Monsanto, Stepan Chemical, and Stauffer Chemical have operated facilities in the town of Woburn or in the Aberjona River drainage basin. Recently a portion of the area was acquired by a local developer who subdivided and sold several parcels for commercial development.

A number of known contaminants were disposed of on-site in substantial quantities. Heavy metals associated with tannery wastes--chromium, arsenic, lead, and zinc--as well as volatile organics and chlorinated organics, were disposed of in the area. It is now suspected that these wastes are contaminating the air, soils, and groundwater, and may be responsible for human health problems in the region.

The Massachusetts Department of Public Health has begun to analyze cancer mortality statistics for this area for the period 1969 through 1978. Age-adjusted death rates for these years were 13% higher than would be statistically expected from 1972 until the present, and the acute childhood leukemia rate is more than double statistical predictions. For the census tract, which encompasses the southern portion of the town, less than one case would be expected in a 15-year period. Eight cases have been observed.

These results suggest that more thorough analysis of the relationships between health and environmental quality be undertaken. Studies[5] are now in progress. Although federal and state consent decrees under wetland protection laws have been negotiated to deal with about 250 acres of the site, a number of additional hazardous sites must be investigated further.

Montague, Michigan

1.2 million cubic yards of hazardous materials were dumped on an 880 acre site by Hodren Chemical Corporation near Montague, Michigan. State officials estimate that 20 billion gallons of groundwater have been contaminated. Heavy rainfalls often wash up to 800 pounds of wastes into nearby White Lake, which drains into Lake Michigan. Dioxin, chloroform, carbon tetrachloride, mirex, and other contaminants are present at the site. Twelve wells have been closed and a warning placed on eating fish from White Lake. The site has produced the highest dioxin levels ever recorded in the state of Michigan.

Jackson Township New Jersey

In 1972, the Jackson township municipal landfill was licensed by the New Jersey Department of Environmental Protection (NJDEP) to accept sewage sludge and septic tank wastes. But chemical analysis of underlying groundwater indicate that there has been chemical dumping. The landfill was recently closed to all wastes.

Table 33. Montague, Michigan

	Information and Data Sources	Comments
<u>Sources of Pollution</u>		
Initial Release	Releases occurred over almost 20 years; order of magnitude estimates, based upon 1965 and 1968 studies by the Deep Well Pollution Control Corp., may be feasible.	
Secondary Sources (Aquifer Water)	Michigan Water Resources Commission study; the Michigan Department of Natural Resources has also done work on the area.	
<u>Transport Mechanism</u>		
Transport in Aquifer	Michigan Department of Natural Resources and USGS data available.	
<u>Damage Categories</u>		
Health Effects	Residents report nausea and headaches; animal test data suggest important health risks.	
Capital Losses	Losses in fishing in lake, replacement water costs, tourism off 15-25%.	

Table 34. Jackson Township, New Jersey

	Information and Data Sources	Comments
Sources of Pollution		
Initial Release		
Secondary Sources (Aquifer Water)	EPA cleanup project in progress; data from this effort are available.	
Transport Mechanism		
Transport in Aquifer	Same as above.	
Damage Categories		
Health Effects	Residents claim premature deaths, kidney problems, rashes, etc. from exposure.	
Capital Losses	Alternative water supply costs, over 100 wells serving over 1,000 people closed, 146 families using bottled water.	

The landfill abuts the Rideway Branch of the Toms River and overlies the Cohansey Aquifer; at present that aquifer is the sole source of drinking water for Jackson Township. The soil is composed of porous sands, and there are no natural or manmade liners to prevent the migration of toxic chemicals from the landfill into drinking water wells. As of August 1980, water was still being trucked into the community.

Approximately 100 drinking water wells surrounding the landfill have been closed because of organic chemical contamination. Analyses of water samples have established the presence of chloroform, methylene chloride, benzene, toluene, trichloroethylene, ethylbenzene, and acetone. Residents claim that premature deaths, kidney malfunctions, kidney removals, recurrent rashes, infections, and other health-related problems are due to the contamination of their water supplies by the landfill. Although use of the wells for drinking water has been banned, residents are still using well water for bathing, dishwashing and irrigation because no other dependable source of water exists.

The state is taking legal action against the township. Recently, the landfill was closed. Residents were drinking the well water until November 1978 and had been bathing with the water until January 1980. A $1.2 million substitute water supply system is planned for the affected residents. However, the township anticipates that the 100 residents may have to bear the costs of the state low-interest loan. No action to restore groundwater quality is contemplated.

Plumstead Township, New Jersey

Rural Plumstead Township, New Jersey, was the site of four hazardous waste dumps in the late 1960s into the 1970s. With groundwater only 15 to 20 feet beneath the sandy soil surface, contamination by the approximately 5,000 cubic yards of waste at the site occurred quickly. There are private wells within three quarters of a mile from the site.

Plumstead is also the site of a major cleanup effort by the state of New Jersey, and thus information on contaminant levels should be relatively accessible. Moreover, attempts to clean the groundwater have required development of data on the hydrology of the area.

Toone, Tennessee

In 1964, a large fish kill in the Mississippi River was traced to pesticide wastes dumped by the Velsicol Chemical Company plant in Memphis, Tennessee. Velsicol subsequently established and used a dump site in Toone, Tennessee, a small Hardeman County community. Among the chemicals dumped at the Toone site are eldrin, dieldrin, heptachlor, and hexachlorocyclopentanene.

The isolation of those residuals at the Toone site is unfortunately far from secure. Leaching of the above chemicals through the soil at the site

Table 35. Plumstead Township, New Jersey

	Information and Data Sources	Comments
Sources of Pollution		
Initial. Release	New Jersey Department of Environmental Protection estimates.	
Secondary Sources (Aquifer Water)	New Jersey Department of Environmental Protection estimates.	
Transport Mechanism		
Transport in Aquifer	New Jersey Department of Environmental Protection estimates; developed during attempts to cleanse groundwater.	
Damage Categories		
Health Effects	Site is in a remote area; little human exposure.	
Capital Losses	Destruction of groundwater resource, cleansing operation costs.	

Table 36. Toone, Tennessee

	Information and Data Sources	Comments
Sources of Pollution		
Initial Release	State of Tennessee Department of Public Health	Department has made estimates of contents of dump site as of date on which dumping was halted. Chemical composition of releases is knoen from analyses of aquifer water.
Secondary Sources (Aquifer Water)	State of Tennessee Department of Public Health study, completed October 1978; further studies in progress.	Officials of Department have expressed willingness to share results of ongoing studies.
Transport Mechanism		
Transport in Aquifer	United Stated Geological Survey (USGS).	USGS monitoring of toxics transport at site dates to at least 1967 when initial danger of infiltration was cited; there has been subsequent work on migration of toxics in the aquifer.
Damage Categories		
Health Effects	Toxicological studies on chemicals released to aquifer; exposure and epidemiological studies by the Center for Health Sciences, University of Tennessee and Center for Disease Control, University of Cinncinatti.	Many of these chemicals have already been studied so that potency results are available

Table 36. (continued)

	Information and Data Sources	Comments
Damage Categories (continued)		
Capital Losses	Residential property losses estimated by State for purposes of compensation; value of aquifer services.	Residential property values available from both State estimates for compensations and existing local valuations; estimate of the value of aquifer services available from costs of alternative water supplies.

and into the aquifer supplying the community's drinking water requirements has occurred. This possiblility was recognized as early as 1967, when the United States Geological Survey determined that a shallow water table lying between the dump site ground and the aquifer was contaminated. Only in 1974, when the local residents complained of foul-smelling water, was it recognized that aquifer contamination--and human exposure through drinking water--was present. Only then was a new source of drinking water substituted for water drawn from the contaminated groundwater.

Table 36 summarized the information available on the Toone episode. Both state and federal agencies have developed information on releases to the aquifer from the dump site and on contaminant levels in drinking water wells. Somewhat unusual is the availability of (acute) health-effect studies based upon direct observation of the exposed population.

Gray, Maine

In September of 1977, the McKin Company was ordered to close by town officials of Gray, Main, due to drinking water well contamination associated with the company's chemical waste site. The McKin was built in 1972 to process waste oil from the Tamano oil spill in Casco Bay. From 1972 until 1977, it was operated primarily as a transfer station for fuel still bottoms. Liquids stored in existing tanks were mixed together for final shipment to re-refiners. Approximately 100,000 to 200,000 gallons were annually processed by McKin at the Gray site.

There is evidence that chemicals spilled from the processing facility have leached into the groundwater aquifer. An unpleasant taste and offensive odors in the drinking water were reported in 1974. Samples of drinking water were submitted to the state laboratory for testing, but the contaminants were not identified. The well water discolored laundry, and some residents turned to alternate sources for their water supply.

In 1977, tricloroethane, tricloroethylene, freon, acetone, xylene, dimethyl sulfide, trimethylsilanol, and alcohols were identified in drinking water. Toxic organics were detected in eight domestic wells within 2,000 feet of the McKin Company. The town health officer subsequently ordered sixteen contaminated wells in the area capped. Traces of many of these same chemicals have also been found in the town's public water supply. Contaminants are thought to have leached into the water table from the town dump where the company disposed of its chemical wastes.

Remedial measures have been undertaken. The town has installed an alternative water supply to the threatened homes in the area at a cost of approximately $600,000. Half of the funding was committed by the U.S. Department of Housing and Urban Development (HUD). Additional costs for cleanup of the McKin facility have been estimated at $50,000.

Table 37. Gray, Maine

	Information and Data Sources	Comments
<u>Sources of Pollution</u>		
Initial Release	Estimates by town and state officials.	
Secondary Sources (Aquifer Water)	Data from cleanup project.	Project carried out by town, half funded by U.S. Department of Housing and Urban Development.
<u>Transport Mechanism</u>		
Transport in Aquifer	Data from cleanup project.	
<u>Damage Categories</u>		
Health Effects	Skin rashes, loss of balance, and liver and bladder disorders associated with exposure to the chemicals found in the water have been reported.	
Capital Losses	Replacement water supplies for residents.	

NOTES

[1]These standards are based on a risk assessment of a one in a million cases of cancer per year based on lifetime exposure (seventy years) of two liters of water per day per person; personal communication; Nassau County Health Department.

[2]The Long Island aquifers are designated sole source aquifers by the U.S. Environmental Protection Agency.

[3]Personal communication, Santa Ana Regional Water Quality Control Board.

[4]Section 311(k) of the Federal Water Pollution Control Act, as amended.

[5]We have received a draft of an epidemiological study from Woburn officials.

APPENDIX B

KEPONE CASE STUDY DATA APPENDIX

INTRODUCTION

This appendix brings together Kepone case study data, identifying sources and gratuitously commenting on peculiarities in, and deficiencies of, those data. We march through data on Kepone production and release, James River and James River flow, Kepone toxicity and persistence, and population exposure and (James River and Chesapeake Bay) fishery data, more or less in that order. The order is a natural one for the damage calculations which are the object of our enterprise.

KEPONE RELEASE AND PRODUCTION DATA

Table 38 summarizes what we know about Kepone production from the plant at Hopewell. That table is divided into tables 38a and 38b because, in 1974, production ceased at Allied Chemical's Semi-Works plant and began, under license, at the Life Sciences plant. This data was assembled in EPA (1978).

How should we interpret the two changeover-year production estimates? In 1974, we have production estimates for both the Allied Chemical Semi-Works plant (72,000 kg) and the Life Sciences plant (384,020 kg). Here is a plausible intepretation, which may even be correct: Life Sciences took over the plant, and expanded production to--actually above--previous levels.

Of course the production data is interesting only as a guide to guesses at, and to the interpretation of, release data. Before turning to that release data, note that actual plant operating practice may not have changed drastically with the changeover in control: there seems little doubt that releases of Kepone into the James began as early as the initial year of operation, 1966, and continued until the plant was closed by Virginia authorities in 1975.

KEPONE RELEASE DATA

Release data is very easy to summarize: we have almost none. What is available for purposes of estimating--or reconstructing--releases of Kepone into the James over the period 1966-1975? Only two kinds of evidence: the

Table 38. Kepone Production at Hopewell, Virginia

Table 38a. Kepone Production at the Allied Chemical's Semi-Works Plant, 1966-1974

Year	Kepone Production (kilograms)
1966	35,935
1967	47,990
1968	36,535
1969	46,990
1970	41,460
1971	204,800
1972	176,970
1973	100,435
1974	72,260
TOTAL	762,875

Table 38b. Kepone Production at the Life Science Plant, 1974-1975

Year	Kepone Production (kilograms)
1974	385,370
1975	384,020
TOTAL	769,390

releases into the James persisting after closure of the plant, and estimates of the amount of Kepone currently residing in James River sediment.

The former number would naturally be suspect as a guide to what the plant actually released while it was operating: it represents continuing releases through the Hopewell primary sewage treatment plant. But the actual number is so small--about 6 grams per day--that this evidence is essentially worthless. At that rate it would take about a thousand years-- 20,000 kilograms divided by 6 grams per day--for even the Kepone currently in James River sediment to be released from the plant. For that reason, our estimates of actual releases, and our probability distributions over potential releases, have been based upon estimates of current Kepone resident in James River sediment.

JAMES RIVER AND JAMES RIVER ESTUARY FLOW DATA

Generally there is an embarrassment of riches of data on flow rates of American rivers. For that state of affairs we have the United States Geological Survey to thank: the Survey's series, of which Water Resources Data for Virginia is the relevant subseries, is the repository of that data. There is very little to complain about regarding data relevant to estimating the probability distribution of fresh-water inflows to the James River.

But of course the James is tidal, or estuarine, just above the location of Hopewell, Virginia, so that all Kepone releases into the James were in effect releases into the estuarine portion of the river.

Because the Geological Survey's "natural jurisdiction" does not extend below the river fall line and thus does not extend into the estuary, we do not have a data base on estuarine flow comparable, in richness and detail, to what we have on the James River in particular (and on American rivers in general). All that we have is one set of data accumulated, for somewhat different purposes, by the Survey, and the measurements on the estuary taken in connection with the Environmental Protection Agency's study of the Kepone problem.

Table 39 below presents the first of those two data sets. In 1971 and 1972 the Geological Survey pulled together one data set including measurements of average monthly net flow at several river sites upstream of the James fall line, at the fall line--Richmond, Virginia--and at the mouth of the James River estuary, where the estuary meets the Chesapeake Bay. The last two values are imputed from data on tributaries flowing into the James estuary. The first three, measured on the river itself, were taken at Buchanan, Bent Creek, and Cartersville.

The second set of data on James River estuary flow was taken in connection with the Environmental Protection Agency's study of Kepone pollution of the James River (EPA, 1978). Figure 20 below locates the sampling stations for this data set, all of them between Hopewell and the turbidity maximum of the James estuary.

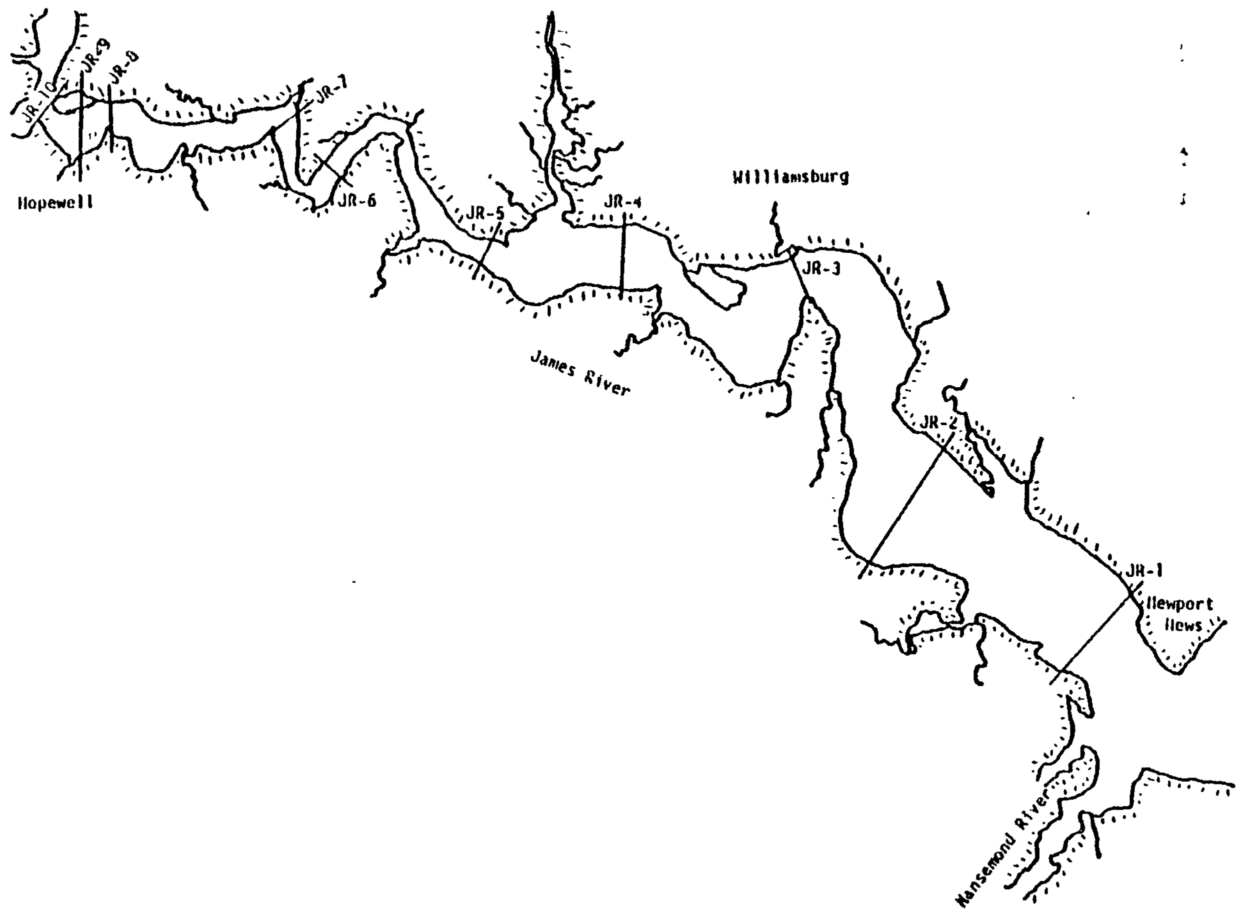
Table 39. James River and Estuary Flow Data, Cubic Feet Per Second

Year	Month	Recording Station				
		Buchanan[1]	Bent Creek[2]	Cartersville[3]	Richmond[4]	ESTUARY Mouth[5]
1971	12	2,659	4,322	7,217		
1972	1	2,745	4,225	6,099	12,804	15,493
	2	6,756	10,590	16,930		
	3	3,276	5,863	9,478		
	4	4,118	6,478	9,608	13,372	16,180
	5	3,779	7,266	12,500		
	6	7,606	3,360	30,330		
	7	3,976	7,280	10,930	20,328	24,597
	8	1,936	3,850	6,757		
	9	660	1,436	2,063		
	10	2,141	5,727	15,010	14,911	18,042
	11	5,807	9,718	18,150		
Annual Average		2,438	4,086	6,931	8,810	10,690

Notes for Table 39:

1. Buchanan, Va., USGS recording station 02019500.
2. Bent Creek, Va., USGS recording station 02026000.
3. Cartersville, Va., USGS recording station 02035000.
4. Imputed from James River tributary inflow data.
5. Imputed from total James River flow and James River estuary tributary flow data.

Figure 20. Location of James River Sampling Stations, Environmental Protection Agency Study



Source: Yasuo Onishi and Richard M. Ecker. 1978. "The Movement of Kepone in the James River," in Battelle Memorial Institute, Pacific Northwest Laboratory, The <u>Feasibility of Mitigating Kepone Contamination in the James River Basin,</u> Appendix A to the EPA Kepone Mitigation Project Report (Washington, D.C., U.S. Environmental Protection Agency).

Table 40 consisting of data summarizing one day's observations at one site for this second data set, illustrates what that set has to offer. At the site labelled JR-1 on the map of figure 20, three stations were set up at three distances from the river bank. At each of those stations, and at each of the three tidal phases--ebb, slack, and flood--measurements were made at several different river depths. The most important of those measured quantities for our purposes are current velocity, suspended Kepone, and supernatant Kepone.

This is perhaps an appropriate place to flag the estuarine modeling issue. That issue is best understood in terms of the following question: what is the appropriate time scale for modeling the kind of major environmental episode that might result in extensive transport of Kepone into the Chesapeake Bay? If it is safe to average over periods long compared with the tidal cycle period, then there is no sense incurring the cost of estuarine modeling. If, on the other hand, it is necessary to get down to the hourly level to model such major episodes accurately, estimates based upon highly time-averaged flow models will misleading.

KEPONE TOXICITY AND PERSISTENCE DATA

What do we actually know about the health and environmental effects of Kepone? Clearly this question is central to our damage-estimation exercise: if the linear dose-response hypothesis is to be believed, human health damage estimates--estimates of the value of incremental human cancer morbidity and mortality risk--will be linear in, e.g., carcinogenic potency.

At the time of the closure of the Life Sciences plant by the Virginia authorities, relatively little was known about the health and environmental effects of Kepone. And in the interim, we have not learned that much more. In this section, we summarize what we do know. We take up human health effects, effects on commercially valuable (and recreationally fishable) species present in the James River and in the Chesapeake Bay, and environmental persistence.

Human Health Effects

In EPA (1978), it was reported that the National Cancer Institute and the National Institute of Environmental Health had proposed, and would shortly begin, a "joint study to re-examine the potential carcinogenicity of Kepone." The 1979 Registry of Toxic Effects of Chemical Substances (National Institute for Occupational Health and Safety, 1980) reported the completion of the National Cancer Institute Bioassay, with positive results found in both rats and mice. These data are compiled in table 41 below.

Effects on Commercial and Recreationally Fishable Species

Here we have only regulatory standards, and not laboratory or field derived information to go on. The inadequacy of those regulatory standards for our purposes is obvious. The standards in question are derived from

Table 40. Results--James River Sampling Program JR-1 James River Bridge June 25, 1977

Station	Tidal Phase	Time	Depth, ft	Current Velocity, ft/sec	Water Temp., °C	Conductivity, μmho	pH	Dissolved Oxygen mg/l	Suspended Solids, mg/l	Suspended Kepone, μg/g	Supernatant Kepone, μg/l
1	Ebb		11.0								
		0825	3.0	1.69		1240	7.3	6.0	42.9		
		0820	8.0	1.35		1250	7.3	5.0	98.5	<0.013	----
	Slack		11.0								
		1110	3.0	1.64		1210	7.4	6.3	40.7		
		1105	8.0	0.90		1210	7.5	6.1	76.4	0.035	----
	Flood		11.5								
		1415	3.0	1.06		1220	7.6	6.1	75.3		
		1410	8.0	0.98		1210	7.6	6.0	87.7	<0.013	0.006
2	Ebb		27.0								
		0915	3.0	1.50		1250	7.6	6.3	34.9		
		0910	10.0	1.18		1250	7.5	5.9	38.4		
		0905	24.0	1.34		1250	7.4	6.8	44.1	<0.011	----
	Slack		27.5								
		1155	3.0	1.69		1200	7.6	7.1	24.1		
		1150	15.0	1.62		1210	7.5	6.4	25.1		
		1145	24.0	0.37		1270	7.4	5.9	65.6	0.038	----
	Flood		29.0								
		1505	3.0	1.69		1210	7.7	6.7	28.9		
		1500	15.0	1.66		1230	7.6	6.1	40.1		
		1445	25.0	1.08		1220	7.6	6.0	55.6	<0.044	0.006
3	Ebb		32.0								
		1010	3.0	1.27		1230	7.1	6.2	27.4		
		1005	15.0	1.64		1250	7.3	6.1	33.1		
		1000	29.0	0.38		1260	7.2	5.8	44.6	<0.023	----
	Slack		32.0								
		1245	3.0	0.71		1210	7.5	6.7	23.6		
		1240	15.0	0.20		1220	7.5	5.8	45.3		
		1235	29.0	0.56		1210	7.4	5.7	47.7	0.028	----
	Flood		36.0								
		1545	3.0	1.32		1220	7.7	6.8	18.5		
		1540	15.0	1.28		1230	7.7	5.9	53.8		
		1535	33.0	1.13		1230	7.7	5.9	61.2	<0.012	----

Source: Yasuo Onishi and Richard M. Ecker. 1978. "The Movement of Kepone in James River," in Battelle Memorial Institute, Pacific Northwest Laboratory, The Feasibility of Mitigating Kepone Contamination in the James River Basin, Appendix A to the EPA Kepone Mitigation Project Report (Washington, D.C., U.S. Environmental Protection Agency).

Table 41. Acute Toxicity Potency Test Results for Kepone

Test Species	Mode of Dose Administration	Test Results	References
Rat	Oral	LD50:95 mg/kg	GUCHAZ 6,96,73
Rat	Oral	TD60:800 MG/KG	AIHAAP 37,680,76
Rabbit	Oral	LD50:65 MG/KG	PCOC** -,642,66

estimates of human health hazard, and thus are not measures of damage to the species involved. Moreover, as "action levels," they imply a discontiuous behavior of damage functions which seems biologically implausible.

Specifically, those standards are Food and Drug Administration Action Levels. Those levels, established on a species-by-species basis, are summarized in table 42.

JAMES RIVER AND CHESAPEAKE BAY COMMERCIAL AND RECREATIONAL FISHERY DATA

In the wake of the Kepone incident, the Commonwealth of Virginia Health Department prepared an interim report: that report was never circulated, and was provided to us by the Health Commissioner's office. The report presented estimates of the impact--in both quantity and monetary terms--of the Kepone incident.

While the interim report is understandably rough-and-ready in style and presentation, the data presented therein are helpful as starting points for, and as checks upon, our own estimates. For that reason we have recorded the state estimates here, together with some critical materials of our own.

A starting point for any discussion of these issues is the "dockside" on finfish and shellfish landings assembled by the National Marine Fisheries Service of the Department of Commerce. These are of course commercial fishery values. Table 43 below,[1] taken from Gabel (1977), presents National Marine Fisheries Service data (Brey, 1980) for the Virginia Commonwealth Bay Area,[2] along with the state's imputations of the associated wholesale and retail values. The definition of the Virginia Chesapeake Bay Area is presumably that given elsewhere in the report, and reproduced in footnote 2 to this appendix.

The original data source, the compilations of the National Marine Fisheries Service, provides coverage of the whole Chesapeake Bay area. Because publication of annual data has been suspended, we are grateful that William Brey was able to provide us with the data of table 44 through 47; this is data that has been "taken," but not yet scrutinized--or published. Those four tables give both quantity and value data, for both commercial shellfish and finfish, for the years 1976 through 1979.

The interim report (Gabel, 1977) went beyond the retrospective data of the National Marine Fisheries Service, and in fact presented estimates of the losses incurred by the Virginia commercial fishing, sports fishing, and recreational-industries. These are necessarily rough, and understandably so given the setting in which they are prepared. Tables 48, 49, and 50 are taken from the original interim report.[3]

Table 42. U.S. Food and Drug Administration Action Standards for Kepone

Species	Action Standard, Micrograms Per Gram (Parts Per Million)
Crab	0.4
Finfish and Shellfish	0.3

Table 43. Dollar Values of Finfish and Shellfish Taken from the Virginia Chesapeake Bay Area in 1975

	Dockside	Wholesale[1]	Retail[1]
Finfish	$ 8,983,396	$22,458,490	$30,543,546
Shellfish	8,701,183	21,752,958	29,584,022
ALL FISH	$17,684,579	$44,211,448	$60,127,568
Selected Species			
Bluefish	$ 154,196	$ 385,490	$ 524,266
Mehaden	6,425,483		
Croaker	322,112	805,280	1,095,180

Notes for Table 43:

1. Wholesale value estimates at 2.5 times the dockside value and retail values estimated at 3.5 times the dockside values.
Source: Fisheries of the U.S., 1975, 1975 Current Fisheries Statistics #6900, (Washington, D.C., U.S. Printing Office, March 1976).

Table 44. Commercial Shellfish Landings, Chesapeake Bay: Catch by Weight (Pounds)

Date	Virginia, Chesapeake Bay	Virginia, tributaries, except Potomac River	Total Virginia	Maryland, Chesapeake, and all tributaries except Potomac River	Total	Total without Virginia tributaries
1976	17,937,758	9,409,980	27,347,730	34,764,328	62,112,066	52,702,086
1977	27,202,153	10,501,485	37,703,638	32,186,997	69,890,635	59,389,150
1978	25,785,844	11,510,760	37,296,604	32,576,942	69,873,546	58,362,786
1979	29,363,493	11,917,073	41,280,566	38,083,275	79,963,841	68,046,768
1980	45,640,000			43,593,000 [3]	89,233,000	[2]

Table 45. Commercial Shellfish Landings, Chesapeake Bay: Value of Catch (Dollars)

Date	Virginia, Chesapeake Bay	Virginia, tributaries, except Potomac River	Total Virginia	Maryland, Chesapeake, and all tributaries except Potomac River	Total	Total without Virginia tributaries
1976	4,171,499	5,518,800	9,690,299	22,258,327	31,948,626	26,429,826
1977	5,843,525	4,886,845	10,730,370	20,557,251	31,287,621	26,400,776
1978	7,002,995	6,306,207	13,309,202	23,731,656	37,040,858	30,734,651
1979	7,269,004	7,104,204	14,373,208	27,068,808	41,442,016	34,337,812
1980	17,765,000			31,622,000 3	49,387,000	2

Table 46. Commercial Finfish Landings, Chesapeake Bay: Catch by Weight (Pounds)

Date	Virginia, Chesapeake Bay	Virginia, tributaries, except Potomac River	Total Virginia	Maryland, Chesapeake, and all tributaries except Potomac River	Total	Total without Virginia tributaries
1976	388,703,330	18,810,835	407,514,165	6,758,440	414,272,605	395,461,770
1977	453,511,101	23,285,424	476,796,524	9,518,384	486,313,908	463,029,484
1978	414,779,638 1	24,317,788	439,097,426	7,016,881	446,114,307	421,796,519
1979	464,855,575 1	10,518,331	475,373,906	5,815,835	481,189,741	470,671,710
1980	560,659,000 1 2		560,659,000	14,131,000 3	574,790,000	2

Table 47. Commercial Finfish Landings, Chesapeake Bay: Value by Catch (Dollars)

Date	Virginia, Chesapeake Bay	Virginia, tributaries, except Potomac River	Total Virginia	Maryland, Chesapeake, and all tributaries except Potomac River	Total	Total without Virginia tributaries
1976	12,584,181	1,247,783	13,831,964	1,166,643	14,998,607	13,750,824
1977	19,131,828	2,075,217	21,157,045	1,387,723	22,544,768	20,519,551
1978	9,029,699 (1)	2,059,405	11,089,104	1,611,013	12,700,117	10,640,712
1979	24,609,840 (1)	1,810,086	26,419,926	1,381,550	27,801,476	25,991,390
1980	31,831,819 (1)(2)		31,831,819	3,224,000 (3)	35,055,819	(2)

Notes for Tables 44-47:

1. Data for Menhaden are reported separately.
2. Data for columns 1 and 2 were combined in the original report.
3. Includes the catch for Chincoteague Bay; that catch is a small fraction of the total. There has been a change in reporting practice.

Table 48. Employees and Wages Earned in Commercial Fishing in the Chesapeake Bay Area, 1975

	Harvestors	Wholesalers	Total
Number of Employees	5,126[1]	4,584[3]	9,710
Total Wages	$17,684,579[2]	$17,736,639[3]	$35,421,218

Notes for Table 48:

1. This represents full and part-time commercial fishermen.
   Source: Virginia Marine Resources Commission.

2. Source: National Marine Fisheries, U.S. Department of Commerce.

3. Includes both processors and packers.
   Source: Virginia Employment Commission.

Table 49. Employment and Wages in the Chesapeake Bay Area Recreation Industry, 1975

	Number of Employees	Total Wages	Total Expenditures	Total Participants
Sports Fishing[1]	4,5000	unknown	$145,700,000[2]	1,147,000[3]
Hotels[4]	31,457	$33,470,445		
Restaurants[4]	95,670	64,223,245		
Retail Seafood Markets[5]	675	817,817		
TOTAL	132,302	$98,511,507		

Notes for Table 49:

1. Data on the sports fishing industry was supplied by the Virginia Marine Resources Commission.
2. Total expenditures refer to direct and indirect fishing related expenditures only.
3. Participants include all persons 12 years or older spending no less than $7.50 and fishing for at least part of 3 consecutive days.
4. Restaurants include all restaurants--both seafood and nonseafood. Source: Virginia Employment Commission.
5. Source: Virginia Employment Commission.

Table 50. Summary of Kepone Costs Resulting from the Kepone Pollution of Kepone Pollution of the Chesapeake Bay Area, July 1975 through December 1976

Sector	Estimated -Dollar Loss	Estimated Wage Loss	Estimated Job Loss
Virginia Commercial Fishing Industry[2]	$12,475,917[3]	$7,179,777[4]	1,980[4]
Virginia Sports Fishing Industry[2]	15,444,200[5]	9,266,560[5]	486[4]
Virginia Recreation	789,280[8]	789,280[9]	162[10]

Notes for Table 50:

1. All 1976 loss estimates are based on actual 1975 data with a 6% price inflation adjustment.

2. Data relates to that portion of the industry located in the Chesapeake Bay area.

3. Estimates are based on an assumed 15% decline in wholesale sales. Additional losses, resulting from the closing of the James River to the taking of certain species of fish, totaling $2,915,634 have also been included.

4. Wage and employment declines assume a 15% decline in sales. Wages and employment loss estimates are based on 1975 wage and employment data for harvestors and wholesalers. Sources: Virginia Marine Resources Commisssion and Employment Commission.

	Harvestors	Wholesalers
Number of Lost Jobs	1,293	687
Lost Wages	$4,362,112	$2,817,665

5. Assumes a 10% decline in sports fishing in 1976.

6. Assumes wages represent 60% of the total loss.

7. Every $30,000 spent on sports fishing creates 1 job, i.e., a $15.4 million reduction in spending will result in a loss of 486 jobs. Source: Virginia Marine Resources Commission.

Notes to Table 50 (continued):

8. Precise data for the decline in sales was unavailable. Total loss represents only wages lost by hotels, restaurants, and retail seafood markets located in the Chesapeake Bay area.

9. Wage losses are based on the calculated average recreational wage for the Chesapeake Bay area.

10. Assumes a negative multiplier. Every 3 jobs lost in sports fishing results in the loss of one job in recreation. Source: Virginia Marine Resources Commission.

FOOTNOTES

[1]This is table 5 of the interim report (Gable, 1977).

[2]The Virginia Chesapeake Bay Area is defined, in Gabel (1977) as: King and Queen County, Henrico County, Richmond County, Chesterfield County, Surry County, City of Virginia Beach, Accomac County, Charles City County, City of Newport News, City of Norfolk, City of Portsmouth, Essex County, City of Hampton, Gloucester County, Isle of Wight County, James City County, King George County, King William County, Lancaster County, Mathews County, Middlesex County, City of Suffolk, New Kent County, Northampton County, Northumberland County, City of Richmond, York County, and Prince George county.

[3]Tables 48 and 49 of this appendix are respectively tables 6 and 7 of the original interim report.

[4]This is a subtable labeled "Economic Sector" of table 1 of the interim report.

APPENDIX C

PRICE CASE STUDY DATA APPENDIX

INTRODUCTION

The data base for this case study ideally would consist of information on the landfill inventory, the geohydrology of the site, the sampling of the wells for contaminants, the pumping histories of the various private and city wells, drinking water consumption estimates, toxicity, health effects, and population. What is actually available is, of course, far from ideal.

LANDFILL INVENTORY

What went into Price's Landfill? Table 51 below summarizes what was assembled by one source; other, better information may be available, from either the State Department of Environmental Protection, from court proceedings, or both. The information in table 51 appeared in the *Pleasantville (New Jersey) Press* on 18 December 1979. Note that, without concentrations, these waste volumes don't tell us how much of the substances in question were dumped.

SITE GEOHYDROLOGY

To organize what we know about the geohydrology of the Price's case study site, let us imagine that we were set on using a simple model of the Upper Cohansey aquifer, so that what was needed is the model parameters describing that aquifer. An enumeration of those parameters will help us organize the information that we do have on the site. Begin with the formula given by Wilson and Miller (1978). Their model describes an infinite, two-dimensional aquifer with perfect vertical mixing; they assume a continuous, constant source of contaminant, "injected" into the aquifer at the origin. Introduce their notation and variables:

C = concentration of the substance in solution (mass of solute per unit volume of solution), in parts per million (ppm).

m = aquifer thickness, in feet (ft).

f'_m = mass injection rate of pollutant, in pounds per day (lbs/day).

Table 51. Wastes Dumped at Price's Pit, 10 April to 7 May 1972

Substance	Volume (Gallons)
Sewer plant waste	271,000
Paint, solvent, thinner	102,500
Cesspool waste	96,000
Unknown sludges	41,000
Unknown chemicals	38,950
Acetone	16,750
Hexane, acetone	10,000
Dichloride	7,400
Spent methanol	4,000
Phenolic solvent, styrene	4,000
Grease, tar	3,900
Waste glue	3,700
Titanium	3,700
Citeon waste	3,700
Manganese dioxide	3,400
Acid	3,400

Source: *The Pleasantville Press,* December 18, 1979.

x = distance between point source x coordinate and observation point x coordinate, in ft.

a_x = longitudinal dispersivity in x direction of flow, in ft.

a_y = transverse dispersivity in y direction, in ft.

R_t = retardation factor due to ion exchange or adsorption, a factor equal to or greater than 1, no dimensions.

λ = radioactive decay constant, in $days^{-1}$. This equals ln2/365L where L equals half-life of species, in years.

V = uniform groundwater flow rate in x direction, in ft/day. This is calculated from field data according to the equation V = KI/7.48n where K is the aquifer hydraulic conductivity, I is the hydraulic gradient, and n is the porosity.

n = aquifer porosity, a decimal.

1.603 = conversion factor to produce concentrations in parts per million. The units of this constant are $ppm/lb/ft^3$.

Wilson and Miller (1978) assume a point source, uniform, complete mixing in the vertical direction, negligible molecular diffusion, and an argument r/B of the function W(u, r/B) much greater than one.

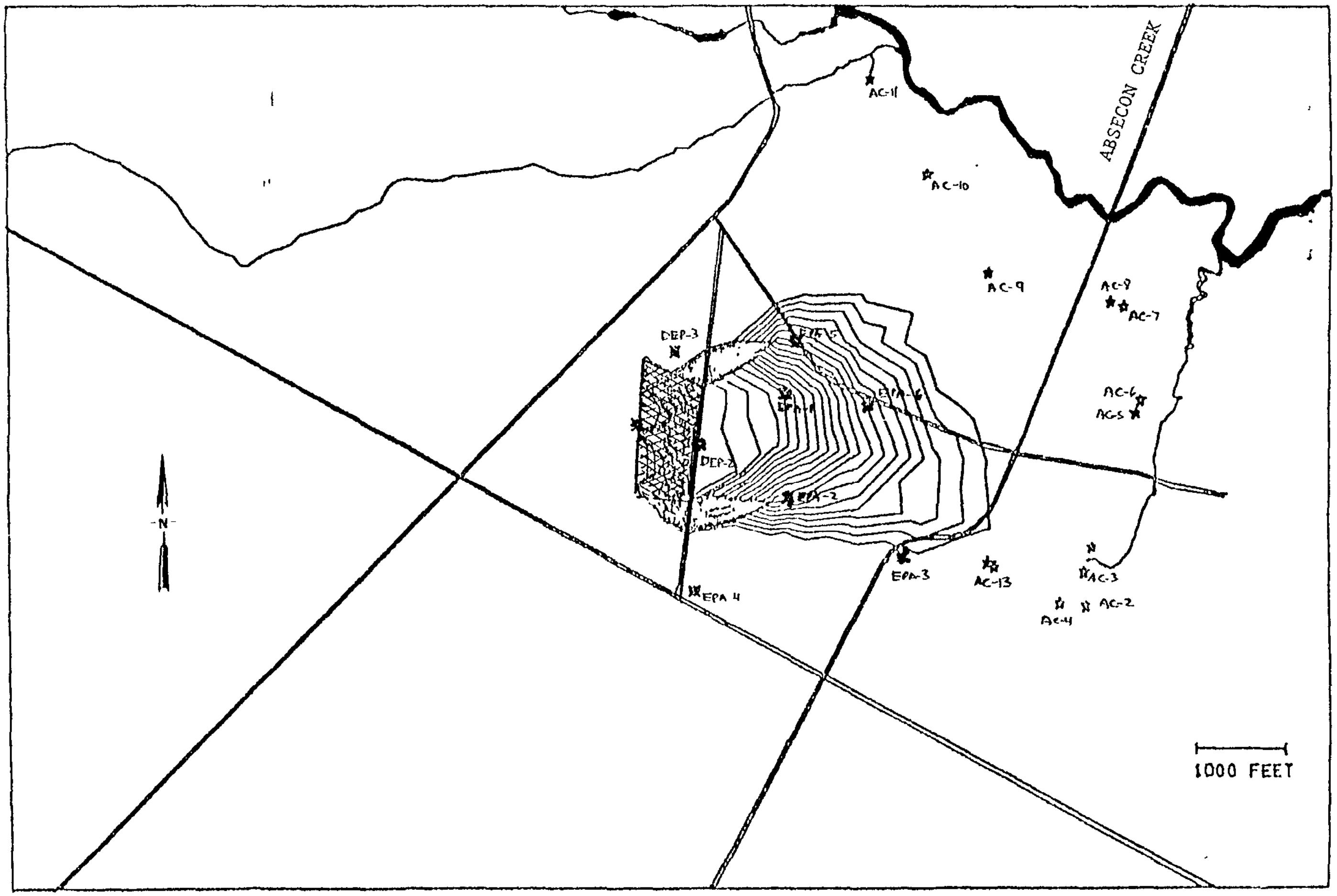
Now look at the variables and parameters of the formula for the concentrations of contaminants. These include surface topography and aquifer characteristics. The latter category divides naturally into flow (velocity and hydraulic gradient) characteristics and geophysical characteristics.

Surface Topography

Application of this or any other formula will obviously require the location of all wells relative to the source term. Figure 21 below, derived from the report (to the Atlantic City Municipal Water Authority, undated) by the consulting firm Paulus, Sokolowski, and Sartor, show the location of those wells along with the extent of the containment plume. Measuring from the approximate center of the landfill, with the x-axis taken as due east, we construct the locations- of the EPA observation, Atlantic City production, and private drinking water wells. Those coordinates are summarized in table 52.

The well names are, for the most part, the names of the owners and/or operators. In particular, for the public agency observation or production wells, DEP stands for the New Jersey State Department of Environmental Protection, EPA stands for the United States Environmental Protection Agency, and AC stands for the Atlantic City Municipal Water Authority.

Figure 21. Well Locations



Source: Paulus, Sokolowski and Sartor. No date. "Geohydrological Study of Contaminant Plume Emanating from Price's Landfill, Egg Harbor Township, N.J.," draft of study done for Atlantic City Municipal Utilities Authority.

Table 52. Locations of Public Production and of Observation Wells

Well Name	Well Location (Feet from Center of Landfill) X	Y	Z
DEP1	-350.	175.	.
DEP2	300.	-50.	25.
DEP3	1000.	75.	15.
EPA1	1375.	550.	41.
EPA1A	1375.	550.	41.
EPA2	1400.	-650.	42.
EPA3	2725	-1275.	40.
EPA3A	2725.	-1275.	76.
EPA4	325.	-1700	100.
EPA5	1450.	1150.	10.
EPA5A	1450.	1150.	23.
EPA6	2325.	450.	55.
AC2	4850.	-1850.	82.
AC3	4800.	-1850.	193.
AC4	4550.	-1850.	90.
AC5	5375.	325.	.
AC6	5425.	475.	.
AC7	5225.	1575.	177.
AC8	5075.	1625.	77.
AC9	3650.	1925.	177.
AC10	2950.	3050.	178.
AC11	2250.	4100.	177.
AC13	3700.	-1350.	75.
A1	0.	0.	250.

Well Name	Well Location (Feet from Center of Landfill) X	Y	Z
A2	4400.	-1250.	230.
A3	1900.	2125.	245.
A4	-475.	-700.	138.
C1	450.	225.	120.
C2A	4400.	-1275.	100.
C2B	4400.	-1275.	60.
C2C	4400.	-1275.	30.
C3A	1950.	2200.	97.
C3B	1950.	2200.	60.
C3C	1950.	2200.	30.
C4A	1925.	-2350.	190.
C4B	1925.	-2350.	100.
C4C	1925.	-2350.	60.
C4D	1925.	-2350.	30.
C5A	3750.	450.	190.
C5B	3750.	450.	100.
C5C	1875.	450.	55.
C6	1400.	1175.	100.
C7	2250.	425.	107.
C8	3275.	650.	96.
C9	-1200.	1825.	.
P2	3700.	-1275.	190.
P3	4950.	-1275.	135.
P4	5150.	-1775.	97.
P5	5500.	-2050.	190.
P6	4950.	-1100.	189.
P7	4625.	-900.	190.
P8	4400.	-650.	100.
P9	5000.	-1300.	.
P10	5750.	-1300.	95.
P11	5250.	-1000.	190.
P12	4950.	-1125.	.

The well coordinates are in feet, measured from an origin located at the approximate center of the landfill. The well depth, or z coordinate, is positive downwards, and measured from ground level.

WELL PUMPING HISTORIES

For computing historical exposures, we need contaminant concentrations at the drinking water wells, well pumping histories, and chemical treatment histories. The latter will be difficult to reconstruct; the former can be built upon measured contaminant concentrations.

Regarding the well production histories, we have only some rough information on current rated capacities. That information, for both Atlantic City drinking water wells and the City's reservoirs, is summarized in table 54 below. Some addition information must be checked and interpreted. At least three wells--AC1, AC5, and AC6--are officially listed as Out of Service. It is not clear if the current contamination problems are to blame, or if other, unrelated problems are relevant. And we do not know which aquifer those wells were screened in.

For the City reservoirs, we have a rated capacity of 0.9 million gallons per day, listed as a safe yield capacity. For a crisis of a month or less in duration, that can be stretched to 13.0 millions of gallons per day. The latter figure is the maximum allowable diversion for any one month.

WELL SAMPLING DATA

Following the discovery of contamination of the Upper Cohansey aquifer by leachate from Price's Landfill, several independent efforts were made to determine the extent of the contamination. These all involved taking samples from wells, chemical analysis of those samples, and to some extent construction of a model of plume movement.

Our data base on contaminant concentrations in well water is easy to describe. For several wells, on each of several days, measurements were made of concentrations of all of the Environmental Protection Agency Priority Pollutants. A complete printout of the data base is included in this report, but that record is of course very "sparse"; there are many zero observations, corresponding to zero (or unobservably small) concentrations of contaminants, on many dates, in many wells.

Strictly speaking, those zeros are "valuable information," and should be included in any effort to estimate geohydrological parameters or contaminant inflows. But in the early stages of data interpretation, those abundant zeros make it very hard to see anything at all in the data. For that reason, we have sorted the nonzero observations by chemical, for the chemicals that show up (in any of the wells) with the highest concentrations. That sorted record, too, is included as part of this report. Something of the "feel" of that data can be gotten from looking at the sorted record for a few

Table 53. Locations of Private Production Wells

Well Name	Well Location (Feet from Center of Landfill)		
	X	Y	Z
LCH	300.	0.	0.
AMBRUS	2000.	0.	30.
MATHEW	1450.	600.	30.
OW1	950.	-400.	203.
WETZEL	1700.	-750.	30.
GARRETT	300.	750.	30.
JOHNSON	400.	900.	35.
JOHNSON2	400.	900.	35.
QUATER	550.	1300.	30.
EAGLE	575.	1400.	30.
WHITEE	575.	1400.	30.
HALL	625.	1500.	30.
WOOD	675.	1625.	30.
WHITEJ	675.	1625.	30.
WHITEO	675.	1625.	80.
MCWILL	725.	1750.	30.
AMES	750.	1850.	86.
WHITEW	-850.	850.	80.
GAINS	-1050.	1050.	30.
DORSEY	-1050.	1050.	30.
GARRET	-1125.	1125.	30.
MARK	-1175.	1175.	30.
FIELD	-1225.	1225.	25.
MARTYN	-1350.	1350.	30.
NJWC3	0.	-4500.	50.
SPENCE	-1400.	-1400.	30.
JOHNSN	-1400.	-1400.	30.

Table 54. Rated Capacity for Atlantic City Wells and Reservoirs

	Well	Maximum Daily Output (Millions of Gallons)
Upper Cohansey Aquifer Wells	AC2	1.0
	AC4	0.6
	AC8	1.2
	AC13	1.0
Lower Cohansey Aquifer Wells	AC3	1.5
	AC7	0.9
	AC9	1.1
	AC10	1.6
	AC11	1.1
	AC12	1.5
Kirkwood Aquifer Wells	AC14	1.2
	AC15	1.0
Reservoirs		9.0

chemicals. In table 55 we present four, the four which show up in the highest concentrations in any well at any date.

TOXICITY AND HEALTH EFFECT DATA

For the chemicals and metals on the Priority Pollutant list, the United States Environmental Protection Agency has promulgated health-related standards expressed run in terms of ambient concentrations. Specifically, estimates are made of the concentrations which, for lifetime exposures, will produce one additional cancer incidence in a population of 100,000. In other words, lifetime exposure at the concentration embodied in the standard "endows" an exposed individual with an incremental 10^{-5} cancer risk over his or her lifetime.

In the tables below, we have compiled those standards for the chemicals detected in the wells around the Price site. Some additional information relevant to modeling the transport of the individual chemical is also included.